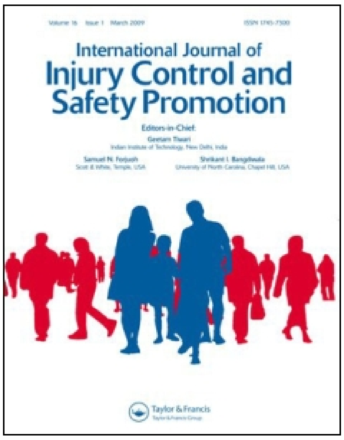

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Machine-related injuries in the US mining industry and priorities for safety research

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Machine-related injuries in the US mining industry and priorities for safety research

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Researchers at the National Institute for Occupational Safety and Health studied mining accidents that involved a worker entangled in, struck by, or in contact with machinery or equipment in motion. The motivation for this study came from the large number of severe accidents, i.e. accidents resulting in a fatality or permanent disability, that are occurring despite available interventions. Accident descriptions were taken from an accident database maintained by the United States Department of Labor, Mine Safety and Health Administration, and 562 accidents that occurred during 2000–2007 fit the search criteria. Machine-related accidents accounted for 41% of all severe accidents in the mining industry during this period. Machinery most often involved in these accidents included conveyors, rock bolting machines, milling machines and haulage equipment such as trucks and loaders. The most common activities associated with these accidents were operation of the machine and maintenance and repair. The current methods to safeguard workers near machinery include mechanical guarding around moving components, lockout/tagout of machine power during maintenance and backup alarms for mobile equipment. To decrease accidents further, researchers recommend additional efforts in the development of new control technologies, training materials and dissemination of information on best practices.

Keywords: mining; machinery; equipment; accidents; safety

1. Introduction

Although the total number of mine worker fatalities in the United States, as well as fatality incidence rates, have trended downward during the past 20 years, the proportion of these accidents involving mine machinery and mobile equipment has consistently been significant (Kecojevic, Komljenovic, Groves, & Radomsky, 2007). Researchers at the National Institute for Occupational Safety and Health (NIOSH) have been concerned with the interaction of workers and machinery and with the number of severe accidents classified as struck-by or caught-in (Burgess-Limerick & Steiner, 2006a; Ruff, 2007; Schiffbauer, 2005; Venem, Shutske, & Gilbert, 2006). These accidents include workers entangled in rotating machinery, struck by moving machine components or run over by mobile equipment. An analysis of accident data available from the Mine Safety and Health Administration (MSHA) was conducted to better understand the problem and scope of machinery-related accidents.

Ensuring worker safety near machines is a challenging problem. In many cases it is an industry-accepted practice to allow workers to be near moving machinery in order to perform their jobs. For example, workers often perform cleanup of material near conveyors while the conveyor is operating. Loose clothing or a shovel being used by a worker can get caught in pinch points near idlers or pulleys. Workers and large mobile machinery are often in close proximity, especially in underground mines and smaller surface operations. Collisions between workers and mobile machines occur despite widespread use of backup alarms. Another troubling accident scenario occurs during maintenance when workers are entangled in machine components when the machine is unexpectedly reenergised. Lockout/tagout procedures are required in the mining industry, but are sometimes either not followed or not adequate for a particular machine design. During the past few decades, the mining industry has put in place many types of safeguards to reduce these types of accidents. Yet, challenges still remain as evidenced by the persistent recurrence of certain types of accidents and the significant proportion of machine-related accidents as compared to all accidents that occur during mining.

The goals of this study were to better understand the contributing factors in machinery and haulage

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equipment accidents, assess available safety interventions, propose new ideas if needed, and determine whether certain types of equipment or mines should receive special focus. The following discussion summarises these efforts and provides some suggestions for future intervention research.

2. Methodology

Using the MSHA accident database (MSHA, 2000–2007a), researchers studied accidents that involved machinery and haulage equipment in all types of surface and underground mining. The criteria for selecting accidents included MSHA accident classifications of powered haulage, machinery and hoisting[1] with accident types identified as caught-in/under/between and struck-by/against. Table 1 shows the specific MSHA accident codes used. This first analysis studied accidents involving mine employees (no contractors or office workers) and only included severe accidents (accidents resulting in a fatality or permanent disability). Studying severe injuries allowed researchers to focus the dataset and concentrate on life-threatening problems. Limiting the study to mine employees allowed incidence rates to be calculated using MSHA employment estimates (MSHA 2000–2007b) (employment estimates do not include contractors or office workers). Data from the years 2000–2007 were collected and 562 accidents fit the criteria.

Table 1. MSHA accident data codes.

Degree of injury code	Classification code	Accident type code
01 – Fatal	12 – Powered haulage	01 – Struck against stationary object
02 – Permanent disability, partial or total	13 – Hoisting	02 – Struck against moving object
	17 – Machinery	04 – Struck by falling object
		05 – Struck by flying object
		06 – Struck by rolling object (sliding)
		07 – Struck by powered moving object
		08 – Struck by not elsewhere classified (NEC)
		20 – Caught in/under/between running or meshing objects
		21 – Caught in/under/between a moving and stationary object
		22 – Caught in/under/between several moving objects
		23 – Caught in/under/between collapsing material or buildings
		24 – Caught in/under/between NEC

A subsequent analysis involved studying MSHA fatalgrams and fatal investigation reports for machine-related deaths at surface mines during the same period (MSHA, 2000–2007c). More details are contained in these reports, offering further insight into the worker's activity during the accident, possible root causes and interventions that may have prevented the accident.

3. Results

Figure 1 shows the number of severe machine-related accidents for each commodity mined and includes the breakdown for surface and underground mining methods for that commodity. The highest number of severe accidents involving machines occurred in coal mining (242), followed by stone (136), sand and gravel (83), nonmetal (53) and then metal mining (48). The majority of accidents in coal mining occurred in underground operations, while for other commodities the majority of accidents occurred at surface operations.

Incidence rates per 100,000 employees were then calculated using MSHA employment estimates of total hours worked (MSHA, 2000–2007b) (Table 2) and the assumption of 200,000,000 exposure hours. This gives the number of injuries per 100,000 full-time equivalent employees working 2000 hours per year. Confidence limits for the overall incidence rate were calculated assuming that the accidents studied were distributed as Poisson variables.

Incidence rates for each commodity indicated a fairly even distribution for exposure to haulage and

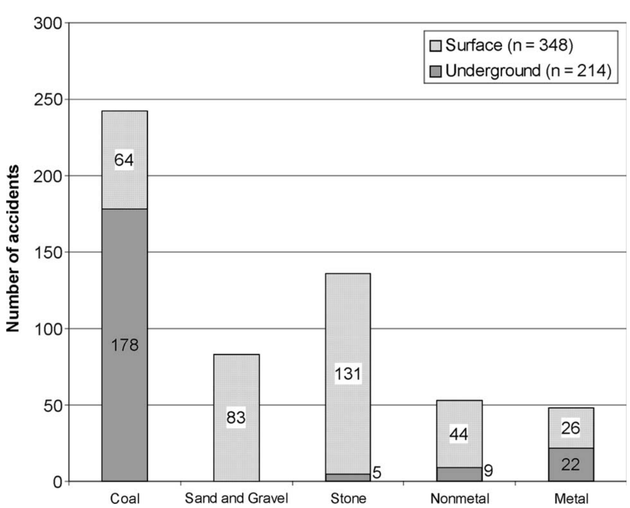

Figure 1. Number of severe mobile and stationary machine-related accidents by commodity, 2000–2007.

machinery-related hazards (first data set of Figure 2). Coal mining had the highest incidence rate of severe machinery accidents (36.8 per 100,000 employees), followed by nonmetal mining (32.0), sand and gravel (30.9), stone (23.6) and metal mining (20.7). This resulted in an average of 29.6 severe injuries per 100,000 employees across all commodities (95% confidence limits (27.2, 32.1)). These machine-related accident rates were then compared with rates for all types of accidents (second data set of Figure 2). On average, severe machine-related accidents classified as struck-by or caught-in accounted for 41% of all severe accidents at mining operations.

Researchers then determined the most common machinery involved in these severe accidents. Figure 3 shows the top 20 machine types and, for each machine, the breakdown for mine type (surface or underground). Eighty (14%) of the 562 accidents involved conveyors with most accidents occurring at surface operations. Roof bolting machines, haul trucks and front-end loaders were most frequently involved in accidents involving mobile machines. The activity of the worker during the accident was also of interest (Figure 4) – a significant portion of injuries and fatalities occurred during maintenance and repair of all types of machines (25%). A closer look at maintenance accidents revealed 4 fatalities and 21 amputations resulting from a machine being unexpectedly restarted while someone was working on it.

Finally, incidence rates for machine-related severe accidents were calculated for mine employment-size classes (Table 3). Small mines with 10 or fewer employees had the highest rate – 41.3 accidents per 100,000 employees. The highest number of accidents occurred at mines with 50–249 employees and that group had the second highest incidence rate.

3.1. *Closer look at surface mining*

Researchers were interested in more detailed injury information regarding machine-related accidents at surface mining operations. Again, the conveyor system was the machine most often involved in severe accidents at surface mines – 18% of the 348 total accidents. Further breakdown showed that for the top three stationary machines involved in accidents at surface mines (conveyors, milling machines and crushers), the most common activity during the accident was maintenance and repair. For mobile earth-moving machinery (trucks, loaders, scrapers and dozers) most of the severe accidents occurred during the operation of the machinery.

Table 2. Total employee hours by commodity, 2000–2007.

Commodity	Total employee hours	Average hours/year
Coal	1,316,232,708	164,529,089
Stone	1,151,639,753	143,954,969
Sand and gravel	537,344,125	67,168,016
Metal	464,622,830	58,077,854
Nonmetal	331,558,981	41,444,873

To better understand these accidents, MSHA fatalgrams and fatal investigation reports for machine-related deaths at surface mines were collected for the years 2000–2007 (MSHA, 2000–2007c). The first analysis concentrated on fatal struck-by or caught-in accidents involving stationary machines and 42 accidents fit the criteria. This analysis provided further insight into the worker's activity during the accident, common machines involved, root causes and interventions that may have prevented the accident. Most of the fatal accidents involving stationary machinery at surface mines occurred at sand and gravel (38%) and stone operations (26%). Entanglement in conveyor components was the most common cause of fatal accidents (48%). These were followed by accidents involving crushers (10%). In 83% of the surface mining fatalities, the worker was performing maintenance or cleanup. In one-third of the accidents, MSHA listed failure to shut down and lock out the machine as one of the contributing factors. Researchers estimated that a system that could detect a worker's proximity to hazardous machine components and provide an alarm or control signal may have prevented almost half of the accidents.

For the second fatality analysis, researchers also used MSHA fatalgrams and fatal investigation reports, but concentrated on struck-by and caught-in mobile machinery fatalities at surface mining operations (MSHA, 2000–2007c). Most of these accidents were due to operators losing control of the machine. Sixty-one fatalities were attributed to brake failure, some other mechanical problem or operator error that resulted in a roll-over or collision. Figure 5 shows the breakdown by machine type. The majority of these fatalities occurred at surface coal operations (44%), followed by stone operations (30%) and sand and gravel (10%), with the remaining accidents split equally between other metal and nonmetal mines.

Another common accident involved operator visibility issues such as collisions or backing over an unseen edge. Twenty-seven fatalities fit this criteria and Figure 6 shows a breakdown of these accidents by machine type. Of these fatalities, 16 involved collisions with workers on the ground or with other vehicles, and 11 involved driving over an unseen edge. The majority (67%) occurred while the machine or vehicle was in reverse motion (Figure 7). These visibility-related surface mine fatalities occurred at coal operations

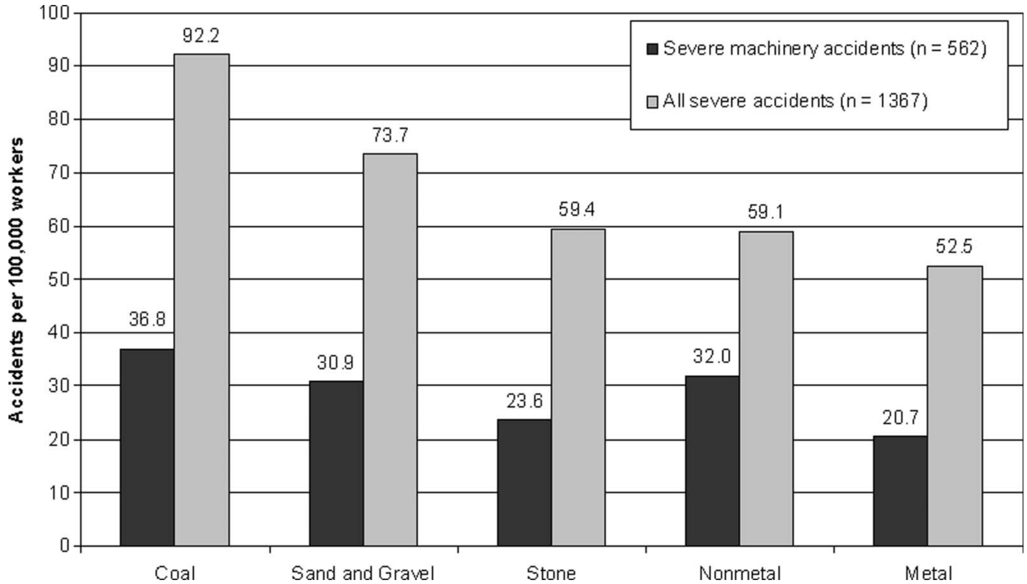

Figure 2. Incidence rates for severe machine-related accidents compared to all severe accidents, 2000–2007.

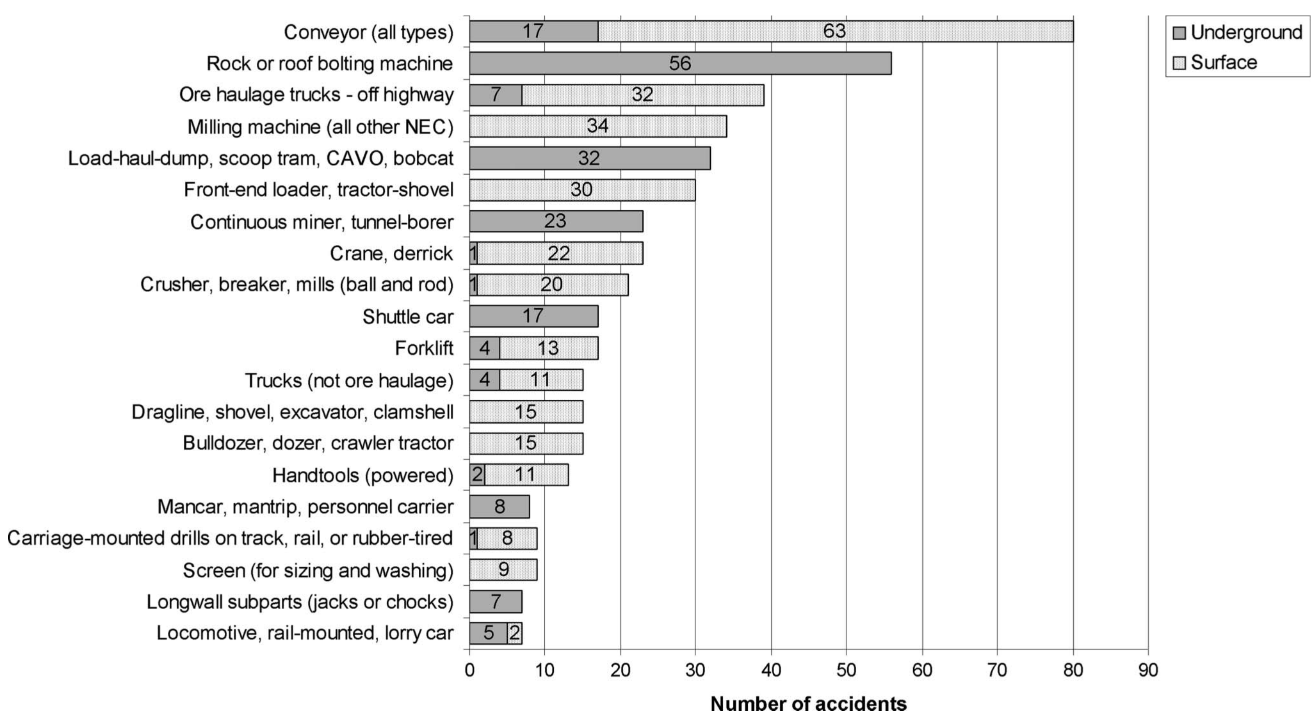

Figure 3. Severe mobile and stationary machine-related accidents by machine involved, 2000–2007 (top 20).

(37%), stone operations (37%), and sand and gravel mines (22%), with one fatality at a mill.

3.2. *Other mine accident studies*

The above findings are in agreement with other studies of mining accidents in the United States. For example, during 1994–2003, machinery and powered haulage equipment contributed to the majority of fatalities in surface stone and sand and gravel operations (Karra, 2006a,b). Machine maintenance and repair and the operation of equipment, such as trucks and loaders, were the most dangerous activities. The study by Karra (2006a,b) concluded that worker activities during maintenance and repair of machines should be a top priority in safety programmes.

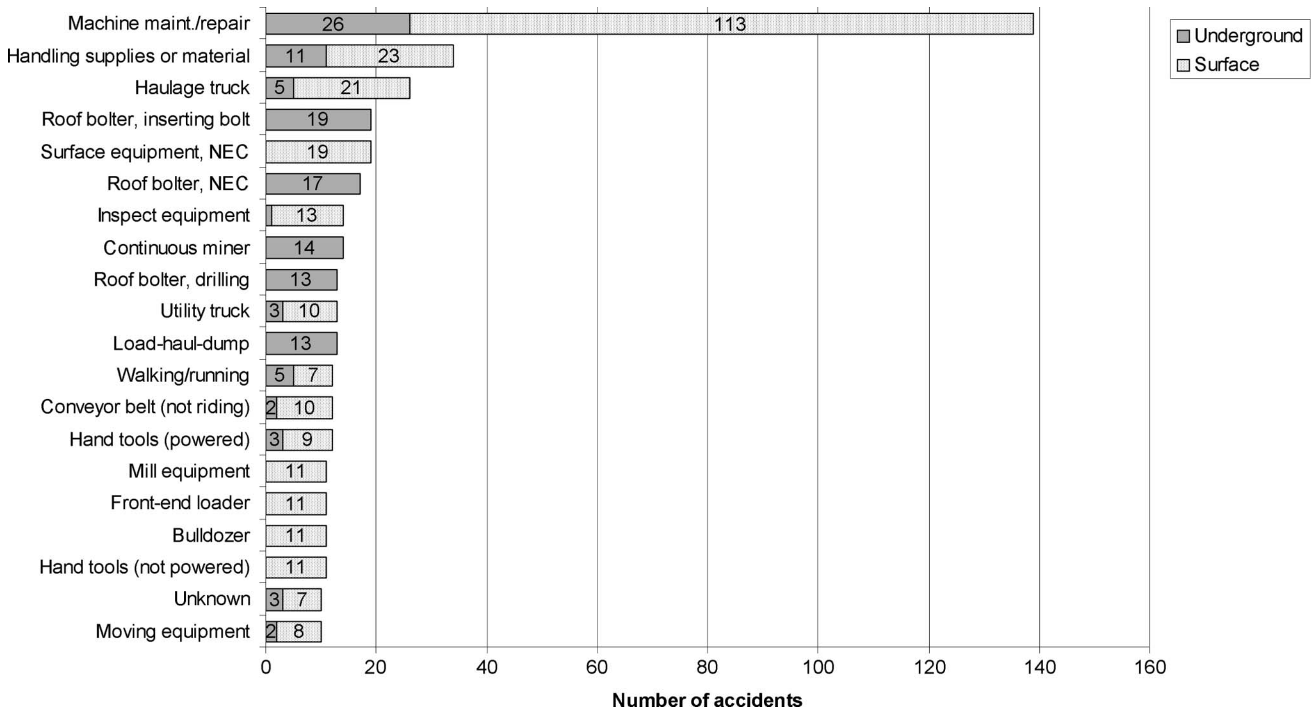

Figure 4. Severe mobile and stationary machine-related accidents by worker activity, 2000–2007 (top 20).

Table 3. Severe machine-related accident incidence rates by mine employment size, 2000–2007.

Number of FTE employees	Number of cases	Total hours worked	Incidence rate per 100,000 employees
10 and below	104	503,464,997	41.3
11–49	148	1,116,799,876	26.5
50–249	210	1,291,845,757	32.5
250–999	95	816,254,434	23.3
1000 and up	5	73,033,333	13.7

Kecojevic et al. (2007) analysed all equipment-related fatalities at underground and surface mining operations in the United States during 1995–2005. Their study showed that the greatest proportion of fatalities involved haul trucks (22.3%), followed by belt conveyors (9.3%). They also examined the relationship between fatalities and mining experience, which showed that miners with less than five years of experience were involved in 44% of the accidents.

Zainalabidin, Kecojevic, Komljenovic and Groves (2008) concentrated on risk assessment for loaders and dozers using MSHA accident data from 1995 to 2006. This study determined that the most frequent hazards for loaders involved failures in following adequate maintenance procedures and failures of machine components. For dozers the most common hazard involved failures to identify adverse site conditions.

Studies of mining accidents in other countries have also highlighted the need to address machine safety issues. For example, Burgess-Limerick and Steiner (2006b) provided an analysis of mobile machinery accidents in coal mines in New South Wales, Australia. That study identified six high-priority hazards: handling cable; strain while bolting; slipping off a continuous miner platform; incorrect operation of controls; rough roadways; and collisions with other vehicles, mine structures, or pedestrians. Another detailed analysis of 103 fatalities that occurred in all Australian mines during the period 1982–1984 was conducted by Mitchell, Driscoll and Harrison (1998). That study found that the most common activity being performed during the fatal accident was travelling for work purposes (to and from the mine and within the mine). Other common activities during the accidents included miners involved in the process of obtaining coal or minerals, and workers performing maintenance or repair. The most common source of the injury was falling objects (34%), vehicle incidents (29%) and being struck by a vehicle or machine component (18%).

Dhillon (2009) has cited statistics regarding fatalities in quarries in the United Kingdom. Vehicle-related fatalities (collisions, travelling over an edge, rollovers) comprised 41% of all fatalities that occurred in those quarries during the period 1983–1993. Workers entangled in conveyor belt components comprised 11% of all fatalities.

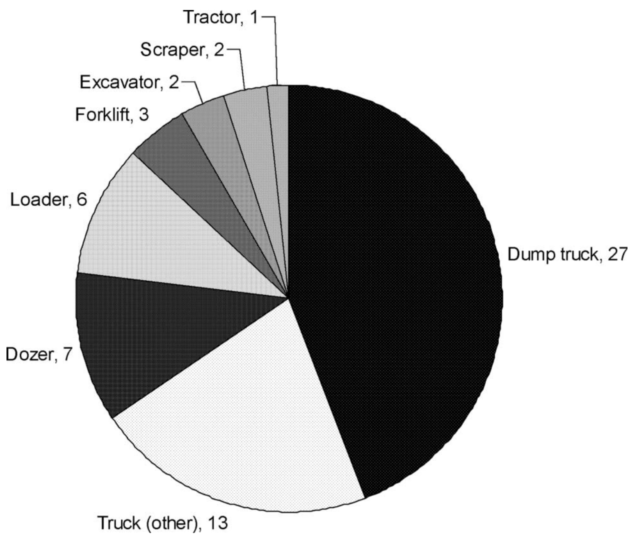

Figure 5. Mobile surface mining machines or vehicles involved in fatal accidents attributed to loss of control, 2000–2007.

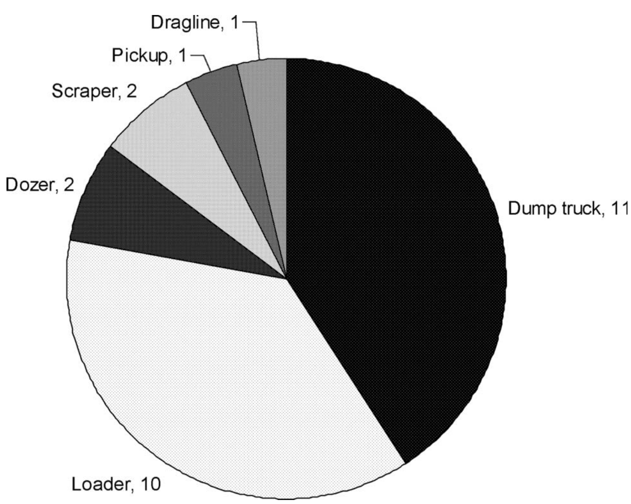

Figure 6. Mobile surface mining machines or vehicles involved in fatal accidents attributed to visibility issues, 2000–2007.

A study by Ural and Demirkol (2008) analysed surface mining accidents that occurred in Turkey. In 2004, 68 fatal accidents occurred in their mining industries, resulting in the highest incidence rate among major mineral-producing countries. The most common fatal accident types in surface mines were reported as blasting operation (18%), powered haulage (16%), fall of ground (14%) and machinery (12%). Recommendations from this study included the need for increased use of personal protection devices, new safety technology, improved training for younger workers and slope stability risk assessment.

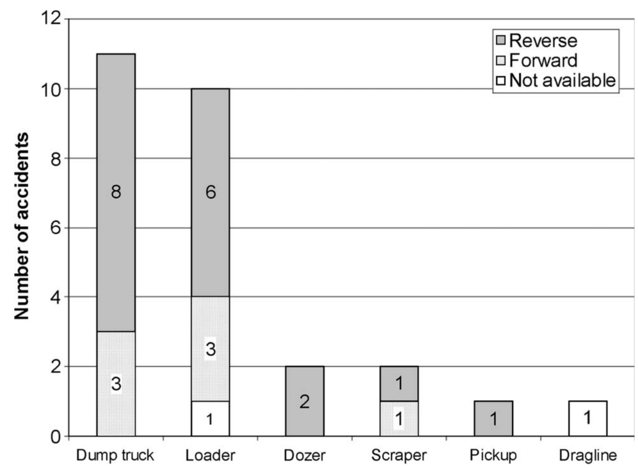

Figure 7. Direction of travel during the fatal accident involving visibility around mobile surface mining machines, 2000–2007.

4. Discussion

To further define the possible research priorities, accident narratives for the MSHA data on severe machine-related accidents in underground and surface mines were studied (MSHA, 2000–2007a). Of the 562 accidents, 259 (46%) occurred during the operation of the machine and 139 (25%) occurred during maintenance or repair. The next most frequent activity during the accident was handling supplies or materials, with 34 accidents (6%). Thus, focus was placed on the top two worker activities during the accident and the top 10 types of machines involved. Suggested research priorities were primarily determined from the information contained in each accident narrative regarding circumstances, type of injury and other factors. Input for priorities was also obtained from related MSHA fatality investigation reports and from interactions with industry. Table 4 summarises the data and suggested research priorities for accidents that occurred during operation of a machine. Table 5 summarises priorities for accidents that occurred during maintenance and repair. A discussion of the suggested research priorities follows.

4.1. *Stationary machines*

Current methods to safeguard moving components on stationary machines at mine sites are numerous. Some methods, such as guarding, are required by MSHA (CFR, 2007). Other safeguards, such as proximity sensors, are recommended or suggested (MSHA, 2004). The most common safety device is a mechanical guard around moving components such as head and tail pulleys, gears, chains, shafts, etc. that prevents a worker from contacting the hazardous

Table 4. Suggested research priorities for severe machine-related accidents (top 10 machines) with activity during accident listed as 'operate.'

Machine	No. of accidents	Suggested research priorities
Rock or roof bolting machine	51	Improved guarding of moving machine components; proximity warning to prevent worker entanglement, pinning, striking
Ore haulage trucks – off highway and underground	28	Proximity warning and/or improved visibility to prevent collisions or driving over an unseen edge, improved training, machine and environment status monitoring to prevent loss of control, operator fatigue detection
Load-haul-dump, scoop tram, CAVO, bobcat	15	Proximity warning and/or improved visibility to prevent collisions or driving over an unseen edge, improved cab design to protect operator
Continuous miner, tunnel borer	13	Proximity warning to prevent operator pinning, striking
Conveyor (all types)	13	Proximity warning and/or improved guarding to prevent worker entanglement, improved lockout/tagout procedures and technology
Bulldozer, dozer, crawler tractor	12	Detection of edges and drawpoints, systems to monitor machine stability, improved seatbelts
Milling machine (all other NEC)	12	Proximity warning and/or improved guarding to prevent worker entanglement, improved lockout/tagout procedures and technology
Trucks (not ore haulage)	11	Machine and environment status monitoring to prevent loss of control, improved training, proximity warning and/or improved visibility to prevent collisions or driving over an unseen edge
Front-end loader, tractor-shovel	11	Proximity warning and/or improved visibility to prevent collisions or driving over an unseen edge, improved seatbelts and training, machine and environment status monitoring to prevent loss of control
Shuttle car	9	Proximity warning or assisted steering/guidance to prevent contact with walls or roof
Top 10 total for 'operate'	175	

area. Emergency stop buttons or pull cords are required on unguarded portions of the conveyor next to travel ways (except in metal/nonmetal mines where railing is an acceptable method to prevent contact). Lockout/tagout procedures to prevent machine movement during maintenance or repair are also required at mines in the United States. In addition, proximity sensors and switches are available to detect when a worker is in a hazardous area, but they are not often used. These include safety mats, bump strips, light curtains, laser ranging devices, radar, sonar, infrared and capacitive sensors.

Despite the requirements for safeguarding machines, accidents at mine sites are still occurring with regularity. There are many factors that contribute to these accidents, but it is believed that improved methods of sensing worker presence in hazardous locations and providing additional accountability for following required safe practices may further impact accidents involving stationary machinery. Innovative engineering controls should be investigated, including human presence sensors and devices that allow workers to remain at a safe distance from hazardous locations while performing maintenance or cleanup. Methods to ensure that a machine guard is in place and improved lockout/tagout training and technology may further decrease these accidents.

Researchers at NIOSH have studied new devices to detect the presence of workers in hazardous areas near stationary machines. Radio transponder or tag-based systems were investigated that use radio-wave or magnetic-field generators mounted near hazardous areas of the machine. Electronic tags are worn by miners that detect the generated marker field and provide a warning when in dangerous proximity to moving components (Schiffbauer, 2005). Another effort investigated the use of intelligent video systems to monitor hazardous locations. Originally developed for security and surveillance applications, these systems use a computer to analyse video images generated from cameras that monitor critical areas around and inside machines. The systems can automatically detect a person entering into predefined zones within the camera's field of view and provide an alarm or a machine control signal. Initial testing showed the ability to provide precise hazardous zone demarcation, the ability to distinguish between humans and other objects in the zone, and the potential to distinguish between hazardous and nonhazardous proximity (Ruff, 2008). Additional work is needed to determine the effectiveness of the technology in the harsh environmental conditions of an actual mine site.

4.2. *Mobile machines*

Loss-of-control of haulage equipment and other mobile machines is a leading source of machine-related fatalities in surface mining (Kecojevic & Radomsky,

Table 5. Suggested research priorities for severe machine-related accidents (top 10 machines) with activity during accident listed as 'maintenance/repair.'

Machine	No. of accidents	Suggested research priorities
Conveyor (all types)	35	Proximity warning and/or improved guarding to prevent worker entanglement, improved lockout/tagout procedures and technology, improved emergency stop controls and activators, remote and/or automatic lubrication, improved material cleanup methods
Milling machine (all other NEC)	17	Improved lockout/tagout procedures and technology, proximity warning and/or improved guarding to prevent worker entanglement, improved material cleanup methods
Crusher, breaker, mills (ball and rod)	9	Improved lockout/tagout technology, proximity warning to prevent worker entanglement, methods to prevent or dislodge jammed material
Front-end loader, tractor-shovel	9	Proximity warning and/or improved visibility to prevent collisions with workers, improved maintenance training (stored energy hazards)
Crane, derrick	8	Detection of overhead power lines, systems to monitor load and stability
Screen (for sizing and washing)	7	Proximity warning and/or improved guarding to prevent worker entanglement, improved lockout/tagout procedures and technology
Pump	7	Improved lockout/tagout procedures and technology
Ore haulage trucks - off highway and underground	5	Improved maintenance training (stored energy hazards)
Forklift	4	Improved maintenance training (stored energy hazards)
Dragline, shovel	3	Proximity warning and/or improved visibility to prevent pinning and striking
Top 10 total for 'maintenance/repair'	104	

2004; MSHA, 2000–2007c). The root causes vary greatly and include mechanical failure, failure to set brakes, weather-related issues, operator fatigue and travelling too fast. In many cases, after losing control of the machine, the operator jumped from the vehicle or simply was not wearing a seat belt. A reduction in these accidents may be achieved through improved training for operators, which has been listed in the literature as a need in the mining industry (Fesak, Breland, & Spadaro, 1996; Kecojevic et al., 2007; Saperstein, 2007). Development of systems to monitor and alert operators regarding the status of safety-critical machine components, machine stability, traffic hazards and road conditions would also be of benefit.

For mobile machines, operator visibility persists as a problem for both underground and surface mining operations. Devices to monitor blind spots near heavy mobile machinery include sonar, radar, radio transponders or tag detection systems, video cameras and GPS technology. Increasing the machine operator's awareness of obstacles, people, and changes in terrain near their machines could reduce these accidents. Only video cameras are used extensively on surface haulage equipment in the United States. Sensor-based warning systems have not been widely accepted because of their cost and complexity. However, the popularity of these devices in both surface and underground operations is increasing worldwide. For example, magnetic field-based proximity warning systems to protect continuous miner operators are now being tested in the United States and implemented in South Africa, and GPS-based proximity warning systems are gaining popularity in surface mines. Ruff (2007) discusses details on available systems for surface mining equipment and guidance for the effective placement and mounting of obstacle detection sensors and cameras.

NIOSH researchers were interested in the effectiveness of backup alarms that are required on mobile mining machines. Laroche (2006) and Purswell and Purswell (2001) also noted issues regarding backup alarms. Of the 16 collision-related fatalities at surface mines, nine occurred while the machine was moving in reverse. All of the machines involved in these accidents that were required to have backup alarms had functioning alarms at the time of the accident (except the scraper backing accident for which this information could not be found) (MSHA, 2000–2007c). Worker habituation to alarms, difficulties in localising and prioritising alarms in congested work areas, and workers wearing hearing protection may all contribute to decreased effectiveness. Despite these concerns, backup alarms have decreased the occurrence of accidents since being introduced. However, the number of accidents that still occur suggests that improvements could be made or supplemental systems should be used to further enhance a worker's awareness of approaching machines and, at the same time, the machine operator's awareness of surrounding obstacles and workers. The additional seven collision-related fatalities show this is also true for the forward motion of the machine, for which backup alarms offer no benefit.

4.3. *Mine size and type*

Coal mining operations have the highest machine-related incidence rates and the highest number of severe accidents, especially in underground operations. Understandably, safety research efforts have and should continue to concentrate on this industry. In addition, the number of machine-related severe accidents at sand, gravel, and stone operations indicates that these mines have challenges that may need more research. Further challenges may be associated with this industry because it predominately operates smaller mines (MSHA, 2006). In fact, 89% of sand and gravel operations operate with 10 or fewer employees (calculated using data from MSHA, 2000–2007b). As shown in Table 3, mines with 10 or fewer employees had the highest incidence rate.

MSHA addressed this issue by creating the small mine office (SMO) in 2002 to help small mining operations develop and implement safety and health programs specific to their needs. Potential challenges for smaller mines include personnel turnover, lower budgets for safety-related training and equipment, and the lack of a full-time health and safety professional. Since the formation of the SMO, the rate of all types of accidents at small mines has decreased (MSHA, 2008). Additional efforts to disseminate best practices and innovative safety solutions could build on the programme's success.

5. Conclusions

Machine safety should continue to be a high priority for mining operations, research organisations, and regulators. Data from this and other studies indicate specific safety challenges with stationary and mobile machinery – severe injuries involving these machines account for more than 40% of all severe accidents at mining operations in the United States. Most severe accidents are associated with the operation or maintenance of the machines. Current research is addressing many machine safety issues in both underground and surface mining. This study identified some specific miner activities and machine types that may need further attention.

With regard to stationary machinery, additional emphasis on safety interventions and training should be directed towards conveyor systems, especially for tasks associated with machine maintenance, repair or clean-up. Innovative sensors to detect the presence of workers near hazardous components should be studied further, along with devices that allow lubrication of components and cleanup of spilled material without requiring workers to be in hazardous proximity to the machine. Innovative methods for ensuring machines are not restarted while undergoing maintenance may build on the success of current lockout/tagout procedures.

For mobile equipment, most fatal accidents occur during the operation of the machine. For example, fatalities involving powered haulage equipment at surface mines, such as trucks and loaders, most often involved loss of control or visibility-related issues. Improved operator training should continue to be pursued and emphasised in mine safety programmes. Improvements in edge detection and collision warning technology, with an emphasis on combining technologies to increase reliability, may increase acceptance (Ruff, 2006; Saperstein, 2007). While backup alarms can offer some protection for workers near mobile machines travelling in reverse, improvements should be investigated to overcome issues such as worker habituation, background noise and accidents involving forward motion of machines. In underground mining, accidents during the operation of roof bolters, loaders and continuous miners are most common. Research should focus on improved guarding of machine components and proximity warning systems to prevent pinning of operators and other workers between the machine and the mine walls.

Finally, machine safety issues at smaller mines and quarries are of concern. Further research efforts could address small mine challenges by evaluating and distributing information on inexpensive and easily implemented machine safety devices. A survey of best practices at the safest mines and the dissemination of unique intervention or training ideas may also be helpful. For this and other intervention research, close partnerships between the mining industry, machine manufacturers, labour organisations, government regulators and research organisations offer the best chance of making significant reductions in mining accidents and injuries.

Note

1. MSHA classifications of machinery, powered haulage and hoisting will be grouped and referred to as 'machinery' or 'machines' in this article. Note that this usage of 'machinery' differs from MSHA usage and in this context includes powered haulage equipment (e.g. trucks, loaders, conveyors), earth-moving machines (e.g. dozers, graders), and stationary machines (e.g. crushers, washers, hoists). Machinery is then further categorised in this article as mobile vs. stationary or fixed.

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