Serious injuries to dozer operators: a discussion of their characteristics and ways to reduce injury risk

W.J. Wiehagen, A.G. Mayton, T.L. Friend, J.S. Jaspal and F.C. Turin
Industrial engineer, mining engineer, private consultant, mining engineer and industrial engineer, respectively, NIOSH Pittsburgh Research Center, Pittsburgh, Pennsylvania

Abstract

This paper describes the serious injuries that have occurred to bulldozer operators working at domestic coal, metal and nonmetal mines in the United States. A serious injury is defined as one that results in either a fatality or in lost work time. Examined were 873 injury records compiled by the Mine Safety and Health Administration (MSHA). The time period covered was 1988 through 1997. These injuries resulted in 18 fatalities and 31,866 lost work days. All of these injuries occurred to dozer operators while they were performing common production tasks. An injury classification system was developed to code the narrative information that describes the circumstances surrounding the injuries. Jolts and jars accounted for 604 or 70% of the serious injuries to bulldozer operators, and jolts and jars accounted for 75% of the workdays lost. Vertical jars comprised the largest set (354 incidents) of jolting and jarring injuries. In more than half of these incidents, the operator was backing up the dozer. Working near an edge carries significant risk for fatal injuries. Of 116 incidents where the dozer fell over an edge, rolled over or fell into a hidden void, 14 (12%) resulted in fatal injuries. In cases where the dozer operator either jumped or was thrown out of the cab in a fallover or rollover, seven out of 17 of the operators were killed. This study finds that further reductions in injury risk would require more widespread use of seat belts; consideration (and maintenance) of the seat and seat suspension systems that might reduce injury risk from jolts and jars; research interventions to assess the effect of alternative engineering designs to dampen or isolate the effects of shock and vibration; and continued attention to skilled performance, i.e., the integration of hazard awareness, recognition and response with dozer operational skills.

Introduction

Bulldozers are a common type of earthmoving equipment. Many of the tasks (e.g., land clearing, roadway construction and ripping) require high levels of operational skill in blade control, machine positioning, hazard recognition and judgment and decision making skills. The work accomplished by dozer operators is essential in that it helps to enhance overall mine efficiency and reduce injury risk for other parts of the mining plan. Dozers are versatile, and the variety of conditions and difficulty of many of the tasks adds both challenges and risk. Dozer operators work in conditions that are dynamic, with hazards that vary and that can be subtle and difficult to recognize. Advances in the application of technologies (e.g., global position systems, on-board computers, software, data radios and receivers) can play important roles in how dozers are efficiently used to move material.

Common hazards that dozer operators face while performing work activities include working on steep slopes or working near an edge, water or hidden voids. There is also the everyday risk of vertical jars and jolts due to uneven terrain, lateral jolts and jars from working material and pushing equipment and the chance of the operator being struck by objects (such as fall of ground or tree limbs) that can contact the dozer or enter the cab. These examples can be characterized as acute, whereby a singular event is identified as responsible for the often unexpected energy release resulting in the incident.

Injury surveillance studies (Sparrell, 1980; Stanevich 1986; May, 1990; Cross and Walters, 1994) have sought to identify the types of injuries and risk to workers while operating off-highway mobile equipment. Each of these studies examined injury data, in part involving off-highway mobile equipment similar to that found at surface mines. The authors' analyses were aggregated across equipment types. While the context for each of these studies is different, their findings are similar. They suggest highly general approaches to reducing injury risk — training, modified work practices, enhanced workstation design and improved ingress and egress. However, none of these studies examined the circumstances surrounding the incidents nor the unique kinds of injuries associated with common bulldozing tasks.

In addition to the risk of traumatic injury, there are other risk factors that involve long-term, cumulative exposures to health hazards. For dozer operators, relevant examples include the potential health impact from exposures to silica dust, noise, cumbersome postures, repetitive control usage and whole body vibration (WBV). The ergonomic literature relating to posture is partially relevant to this paper and is briefly addressed in later sections. Most of the literature on WBV is

Nonmeeting paper number 02-300. Original manuscript submitted for review December 2001 and accepted for publication April 2002. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications Dept. prior to Sept. 30, 2003.

not relevant[1] and the authors presume that the traumatic effects of (short duration) shock, along with the performance limiting effects of vibration, are logically intertwined and difficult to separate.

Likewise, all aspects of the mining system have integrated components. At a broad level, these components involve people, technology and the work environment. Thus, effective efforts to reduce risk are integrated tasks.

Purpose and scope

The purpose of this work is to profile serious injuries sustained by bulldozer operators while performing common production tasks at US mining sites. This paper summarizes information contained in NIOSH Information Circular 9455 (Wiehagen et al., 2001). Both track and rubber-tired dozers are considered. All of the accidents occurred on mine property and were reported by mine operators or independent contractors.

From 1988 through 1997, dozers were involved in 2,962 serious injuries, including 23 fatalities. This is a small fraction of the nearly 80,000 serious injuries incurred by those who work at surface coal, metal and nonmetal mines (Turin et al., 2001). The authors examined 873 records, all of which occurred while workers were "operating dozers." This category is the largest risk category for the broader set of injuries involving dozers. Workers "operating dozers" accounted for 18 fatalities and about 30% (855) of the lost time injuries, which resulted in 31,866 lost workdays. Of particular note, "getting on and off the [dozer] equipment" accounted for the next highest category of serious injury (but zero fatalities). This category accounted for another 30% (875) of the 2,962 dozer-related incidents, which resulted in 30,889 lost workdays.

Method

Two data sets were used in this analysis: fatality reports[2] and lost-time injury records[3], including the actual injury narratives.

A classification system was developed to help organize and summarize the fatality and lost-time injury data. The classification system is specific to dozers and how they are commonly used within mine sites. A qualitative analysis was performed based on the review of the injury narratives[4] to code the records.

Examples of actual injury narratives that can be classified as "acute injuries" are as follows:

> *"Tramming dozer, dozer slid on frozen ground. Went over highwall, dozer fell about 30 ft, and then rolled over. Rollover structure and seat belt held; however, the employee apparently struck his face and fractured left cheekbone."*

> *"Employee was dozing out a ramp on a bench with a dozer he got in close to a previous cut, and a large rock came out of the bank onto the track, causing the dozer to rock back and forth, jerking and straining his neck."*

> *"Employee was operating dozer. He was pushing overburden to high lift. The dozer slid from right to left, then stopped suddenly. When the dozer slid right to left, and then stopped suddenly, it caused a jerk to employee's neck."*

Examples of actual injury narratives that can be classified as "cumulative injuries" are as follows:

> *"Too much strain on back from turning in seat to back up. Too many hours on dozer."*

> *"Injured claimed he was operating a dozer, ripping 2 ft of overburden from off of the Dorchester Seam. While ripping with the dozer, which caused a jerking motion and the operator turning in the seat to watch his ripper, he stated he strained his back."*

> *"The employee was operating a bulldozer performing backfilling operation. During normal operator procedures, employee was turning and twisting while operating dozer. Employee started to experience back pains and swelling of muscles in the lower back."*

In this analysis, injury narratives such as these were coded and summarized as follows:

Activity. What task was being done? (For example, blade/groundwork, ripping, tramming forward, tramming backward or land clearing.) These tasks relate to the primary tasks of bulldozer operation. A default activity — blade/groundwork — was assigned if the narrative omitted specific task information, but it was clear by context that the dozer was used to perform a common production task.

Incident result. What apparently happened to the dozer? (For example, fallover/rollover, vertical jar, lateral jar or normal operations.) If it was apparent that the injury occurred and there was no apparent impact to the dozer, then these records were coded as "normal operations." Examples include injuries due to twisting and turning in the seat, control usage or eye injuries due to dust blowing into the cab.

Operator impact. How was the operator injured? (For example, jolted/jarred, musculoskeletal injuries, struck by an object.) Coding of this field was based on the injury narrative with supplemental information obtained from other fields in the MSHA database (e.g., part of body, nature of injury).

Contributing factors. What factors contributed to the event or severity of the incident? These were identified and coded along the following two dimensions:

- *Event:* factors such as a rock slide, edge failure or hidden void.
- *Severity:* whether the seat belt was on or off.

These variables were in addition to the standard variables (for example, age and experience of the injured worker, mining machine, mine worker activity) that MSHA routinely collects and compiles.

[1] In a recent review of WBV literature, Ranganathan and Mohan (1997) conclude that the ISO standard (2631/1) still remains inapplicable to cases involving high shock levels.

[2] MSHA personnel conduct investigations of every mine fatality.

[3] Title 30, Code of Federal Regulations, Part 50, Section 20. MSHA requires a report to be filed by mine operators or contractors for each accident, occupational injury or occupational illness occurring at a mine site.

[4] Injuries can be characterized as either acute or cumulative. Acute injuries (e.g., fractures and bruises) involve a singular event or a sudden release of energy that results in injury. In contrast, cumulative injuries occur over a period of time. They involve long-term exposure to risk factors (e.g., awkward postures and repetitive control usage) that can lead to (contribute to) serious injury.

Results[5]

Fatality reports. There were 18 fatality reports examined. Of note, there were no fatalities to dozer operators (while they were operating the dozer) in 1996 and 1997[6]. Bituminous coal mining accounted for 11 (62%) of the total. Experience of the worker in the task ranged from only a few days to more than 40 years. Five of the victims had less than two months experience on dozers. Three of these five were on the job for less than a week. Witnesses to the accidents were present in half of the 18 cases. In the other half of these cases, the victims were discovered anywhere from within a few minutes to several hours after the incident.

In 11 of the fatalities, the dozer fell over an edge. In seven of these cases, the operators were found outside of the cab — they either had jumped or were thrown out. A seat belt was not available in the dozer in three of these incidents (the machine had been manufactured before the requirements for rollover protective structures and seat belts). In three other cases, it was noted that the seat belts were not worn.

There were three incidents where the dozer fell into a hidden void. In all cases, the void was bridged. Rescue operations took from two to more than ten hours. For each of these cases, the windows of the equipment were pushed in or broken by the material that engulfed the dozer cab.

Three dozer operators were run over by their own dozer. No witnesses were present at any of these incidents. Investigators concluded that these operators had attempted to exit or enter their machine while the dozers were in gear or that the dozers jumped into gear or the controls were accidentally activated. Failure to take the machine out of gear and set the parking brake was mentioned in two of the reports.

In one case, the dozer hit a (buried) natural gas line, and the operator was killed by the ensuing fire.

Lost-time injury records. Examined were 855 records. These records indicated an average of 102 annual incidents from 1988 to1992 and an average of 69 incidents from 1993 to 1997. This reflects a notable reduction (30%) in the reported number of serious injuries to dozer operators while performing common production tasks at mine sites.

Four states (Kentucky, West Virginia, Pennsylvania and California) accounted for 53% of the total dozer injuries and about the same percentage of the total days lost due to injury. Bituminous coal mining accounted for 62% of the 855 injury records. The injury victims were, on average, 42 years of age. Almost all (99.8%) were male. Median days lost was the largest for the 40 to 49 year old age group. The large majority had a significant amount of total mining experience (greater than five years), although 21% of the lost-time injury victims had one year or less at the particular mine site where the injury occurred. Fifty-seven percent of the incidents involved the neck or back.

Overall, 37 days (on average) were lost for each injury. The median was 19 days.

Dozer activity, incident result and operator impact. Tables 1 and 2 cross tabulate important variables that help in understanding injury risk to dozer operators. Categories related to jolts and jars account for 69% of the serious injuries. In a fallover or rollover, when an operator was jolted or jarred and landed outside of the cab (either by jumping or being thrown out), seven out of 17 sustained fatal injuries. In 142 cases (16%), the operator was jolted to a degree that he struck something (inside the cab). In 12% of the cases (14 out of 116 incidents) where the dozer rolled, fell off an edge or fell into a hidden void, the victim died.

In 102 cases, the dozer operator survived a rollover or falling off/rolling off an edge. About 4,800 days of lost time resulted from these incidents. Of these 102 incidents, a seat belt was mentioned in 11 of the narratives. Nine involved operators wearing a belt. Six of these workers lost seven days or less due to the incident.

In total, vertical jars accounted for 354 injuries, about 40% of the injury set. In over half (185) the injuries resulting from a vertical jar, the dozer operator was backing up. When a dozer fell over or rolled over an edge, backing up was involved in 25% of the cases. Backing up was also involved in about 40% of the cases involving a sudden stop/collision.

Lateral jars of the dozer were identified in 97 of the incidents, with a sudden stop (collision) in 69 cases and the dozer pitching forward or backward in 28 cases. An object (e.g., resulting from a rockslide) struck the dozer in 56 incidents.

For 24% of the incidents, the authors coded those incidents as "normal operations" with *no* apparent impact to the dozer. For the balance (76%) of the incidents, there was some impact to the dozer that resulted in a lost time injury to the operator.

A musculoskeletal injury (MSI) was identified for 155 of the incidents. In all cases, there was no apparent impact to the dozer. These were cumulative type injuries with several of these incidents relating to the operator twisting or turning in the seat, control usage or general situations where the narrative implied a back injury due to dozer usage.

Equipment failure was identified in 29 cases. Hydraulic hoses and seats breaking were predominant in this small set of incidents. In a handful of cases, a fire erupted due to the rupturing of the hydraulic lines near the exhaust manifold or engine. In a few cases involving a fire, the operator jumped from the cab.

Injuries to the back, neck and to "multiple body parts" were most often noted in the MSHA database. Together, these three groupings accounted for 83% (25,960 days) of the days lost. This is not surprising due to the nature and preponderance of injuries within this data set (jolts/jars, struck against, struck by and MSIs).

For the lost-time injuries, median days lost was 25 days for dozer operators in the 40 to 49 age group. Median days lost was 14 days for the 30 to 39 age group and five days lost for younger operators in the 20 to 29 age group.

Summary and discussion

Vertical and lateral jolting and jarring (including those situations where the operator strikes an object inside the cab) are the most common sources of injury to dozer operators while they are operating the equipment. Although the incidents have declined over the time frame (1988 through 1997) studied, this area is still the most opportune avenue for further reductions in injury risk. In total, 604 reported incidents resulted in seven fatalities and 597 injuries. Time lost totaled 23,924 workdays. These were all acute incidents where the operator was im-

[5] For a more in-depth summary, see NIOSH Information Circular 9455 (Wiehagen et al., 2001).

[6] However, for the most recent three-year period (1998-2000), MSHA reports ten fatalities to dozer operators while operating the equipment at US surface mines. Working on a steep slope, near an edge or hidden voids were implicated in eight of these incidents. Age data was available for seven of the ten fatalities: the range is 28 (from 39 to 67) and the median age was 51 and the average age was 55.

Table 1 — Serious incident results by dozer activity (fatalities in parentheses)

Incident result	Dozer Activity: Blade/ ground work	Tramming forward	Tramming backward	Land clearing	Towing/ pushing	Ripping	Total
Fall over/roll over/fall into void	66 (7)	13 (3)	30 (3)	4 (1)	1	2	**116 (14)**
Vertical Jar	127	27	**185**	1	11	3	**354**
Lateral jar (collision)	37 (1)	3	27	1	1	0	69 (1)
Lateral jar (lurch forward/backward)	16	4	3	1	0	4	28
Fire (external source)	2	0	0	0	0	0	2
Normal operations (no apparent impact to dozer)	185	4	14	1	5	3	**212**
Dozer struck by an object	37	0	2	0	14	3	56
Equipment failure	26	0	3	0	0	0	29
Unknown/Other	4 (1)	0	2 (2)	1	0	0	7 (3)
Total	500 (9)	51 (3)	266 (5)	23 (1)	18	15	873 (18)

Table 2 — Serious incident results by operator impact (fatalities in parentheses).

Incident result	Jolted/ jarred	Landed outside of cab	Struck against an object inside cab	Struck by an object	MSI	Burned/ contact with hot object	Asphyxiation or drowning	Other/ unknown	Total
Fall over/roll over/fall into void	31	17 (7)	61	–	–	–	7 (7)	–	**116 (14)**
Vertical jar	**306**	3	45	–	–	–	–	–	**354**
Lateral jar (collision)	54	–	14	–	–	1 (1)	–	–	69 (1)
Lateral jar (lurch forward/backward)	22	–	6	–	–	–	–	–	28
Fire (external source)	–	–	–	–	–	2	–	–	2
Normal operations			4	39	**155**	–	–	14	**212**
Dozer struck by an object	12	–	10	33	–	1	–	–	56
Equipment failure	9	4	2	6	–	6	–	2	29
Unknown/Other	2	2	–	–	–	–	–	3 (3)	7 (3)
Total	**436**	**26 (7)**	142	78	155	10 (1)	7 (7)	19 (3)	873 (18)

pacted in one of the following three ways: the operator was jolted/jarred and remained in the seat, the operator was thrown against an object inside the cab or the operator landed outside of the cab. These accidents account for nearly 70% of the lost time injuries and 75% of the workdays lost.

These findings corroborate another recent study that identified jolts and jars to equipment operators as a significant risk to those that operate mining equipment. Cross and Walters (1994) examined vibration and jarring as a source of back pain in the New South Wales mining industry. Their study involved the review of 28,306 compensation claims over a four-year period (July 1986 through March 1990) and covered both surface and underground environments. They identified 8,961 claims relating to the head, back and neck, of which 11% (986) were due to vehicular jarring. Underground transporters and shuttle cars accounted for 53% of all vehicular jarring injuries. Surface loaders, dozers and dump trucks accounted for another 29% of the vehicular jarring injuries.

MSIs were the next largest category that appeared in the database. Overall, MSIs accounted for 155 incidents. All of these injuries were in situations where nothing external to the dozer contributed to the incident. Further, many of these injuries did not seem to result from a single source — many were related to cumbersome postures, tiring work and difficult dozing conditions. These injuries are often reported as having occurred during the shift and involved back pain.

Zimmermann et al. (1997) reviewed the literature on work-related musculoskeletal disorders (MSD) and WBV among off-highway equipment (OHE) operators. One study referenced (Miyashita et al., 1992) examined work-related disorders for dozer operators. Common ailments among the 127 dozer operator participants included reports of low back pain (36.2%), general fatigue (44.1%) and stiff shoulders (54.3%). Zimmerman et al. (1997) note that the frequency in which WBV is most problematic is in the 4 to 8 Hz range. The authors concluded that the high risk of MSD among equipment operators might be caused by a combination of the sustained and awkward sitting postures and the vibrating environments in which off-highway equipment operators work. Recommendations offered based on their literature review included general suggestions regarding cab and control designs, minimizing vibration exposures and regular breaks by OHE operators.

Fotta and Bockosh (2000) found that older (aged 45+) injured workers have the highest median number of days lost per injury. They examined injury data by type of mining operation and by occupation. For bulldozer operators, there was a notable difference in days lost between the age cohorts (18 to 34, 35 to 44 and 45+). For dozer operators working at surface bituminous coal mining, days lost per incident were seven days for the 18 to 34 year-old workers and 19.5 days for the older group. The data included all types of work activities, while this study examined only those lost-time incidents associated with common bulldozing tasks.

Dozer operators work in conditions that vary, and this presents a significant challenge to the mining community in research, engineering, work practices and self-protective measures on the part of the operator. The following sections discuss what might be done to reduce the risk of injury:

Seat and seat suspension. To reduce the adverse effects of vehicle jarring/jolting for the bulldozer operator, the use of an effective seat with a suspension system is an obvious option. It is a primary way to isolate the bulldozer operator from jars and jolts. Griffin (1990) indicates that all conventional seats amplify vertical vibration because many vehicles possess substantial energy in the 4 Hz region. Seat padding alone is not adequate to attenuate vehicle jarring of the operator. Thus, a mechanical seat suspension complements the seat padding to provide better isolation for the operator. Typically, commercial suspension seats are equipped with a passive suspension system that consist of a damper (shock absorber) and some type of spring. The spring (e.g., a coil spring or torsion bar) is usually constructed of steel or may be provided by a column of air. Passive seat suspensions with steel springs provide the seated operator with the means to manually adjust the spring stiffness to an appropriate value. In contrast, seats with air suspension systems often include a means for detecting the deflection of the seat, and the suspension adjusts automatically to the body mass of the seated operator (Griffin, 1990).

Seat designs for surface OHE have improved significantly with features such as mechanical and pneumatic suspension systems, lumbar spine support and viscoelastic foam padding. Our review of the injury narratives suggests that, regardless of the source, the large majority of jolts and jars seem to come as a complete surprise to the operator. Assessing the usability and performance of such features under different shock and vibration test conditions might offer useful information on ways to better secure the worker.

Some researchers (Gouw et al., 1990) developed computer simulation models to aid designers in the selection of seat suspension parameters. This area of research appears to have some potential in testing certain seating performance characteristics before field application.

There is sizable variability in the price and performance of seats. Seats can range from $200 to $2,000 retail. They can be outfitted with mechanical, air and semiactive seat suspension systems. Seats are available to isolate occupants from jarring and jolting in the fore-aft, side-to-side, as well as vertical directions. Discussions with several seat manufacturers support the notion that many customers buying large industrial off-road equipment are reluctant to invest in a higher-grade seat.

In assessing seat quality, adjustability of the seat is important. Quality seats can be adjusted for such variables as the size and weight of drivers/operators, fore-aft, swivel (where appropriate), arm rests, head rests (where appropriate) lumbar support and adjustability, seat pan angle and backrest angle. Seat padding is also an important consideration for workers who must remain seated for long periods of time. Padding can distribute the seat pressure in a more-uniform fashion, thus enhancing comfort.

Seating manufacturers note that investing in lower-grade seats is fairly common, even though the customer is paying sizable sums for the off-road earth-moving equipment. For farm tractors, they suggest that the more expensive farm tractors typically come with top-grade seating, as opposed to the less-expensive models, equipped with lower-grade seats. Better performing seats will likely cost more.

A benefit-cost (b/c) calculation can offer some insight to the value of a better seat. Although "benefits" are often subjective, estimates can be defined based on projected savings. The value of a b/c analysis is that it allows for a comparison of alternatives by using a common denominator (a way to normalize).

Benefits of a better performing seat can be described as:

- decreased disability cost (workman's compensation);
- decreased absenteeism;
- decreased health-care expenditures;
- decreased turnover — experienced dozer operators stay in the job longer without seeking other (less physically demanding) positions, which can lead to reduced training costs in the long term; and
- increased productivity/lower cost to produce as dozer operators have greater reliance on the seat and suspension system to reduce the level of shock transmitted through the seat, which could help reduce cycle times when the dozer is working in rough terrain.

For example, assume the cost differential of the low-end to high-end seat/suspension system is $2,000. One would assume that there is a marked quality differential in how those seats perform with the more expensive seat significantly reducing the shock transmitted to the operator. One could also assume that the enhanced seat (with suspension) would require some annual maintenance. For the sake of argument, assume the annual maintenance cost is $200 or 10% of the investment.

A benefit-cost calculation would proceed as follows:

$2,000 (5-year life) = extra monies spent on the better seat
$200/year = extra monies to maintain the better seat

Cost = $2,000 + 200 (*P/A*[7], 10%, 5 years)
= $2,000 + 200 (3.791) =
= $2,000 + 758

Cost = $2,758

The question is what annual savings (from the benefit column) would yield a present worth of $2,758?

Benefit = *X**(*P/A*, 10%, 5 yrs) =
= X*(3.791) = $2,758 =

X = $728

Thus, a benefit of $728/year (reduced outlays or the expected benefit) yields a break-even point for the better performing seating investment.

It does not take much annual savings in the "benefit" column to demonstrate a break-even or a positive return. The average and median days lost for an injury due to jolting is 40.1 and 22 days, respectively, and days lost due to an injury increase as the age of the worker increases (Fotta and Bockosh, 2000). One could surmise that the b/c yield is even higher when considering the benefit of an improved seat leading to *better utilization of the dozer*, while preventing health costs down the road.

[7] Present worth factor at 10% compound interest, for 5 years.

Table 3 — Jolting and jarring injuries and seat belt usage (fatalities in parentheses)

Operator impact	Serious injuries	Percent	Seat belt On	Seat belt Off	No Information
Jolted/jarred	436	50	12	3	421
Jolted/jarred - struck against	142	16	8	2	132
Jolted/jarred - landed outside cab	26 (7*)	3	(1**)	(3)	19
Total - jolting and jarring	604 (7)	69	–	–	–
All other injuries	269 (11)	31	–	–	–
Total	873 (18)	100	21	8	572

*Three fatalities involved dozers manufactured prior to the requirement for ROPS
**Investigative report suggested the belt may have torn in the accident

Operator restraint systems. Of the 855 lost-time injuries (Table 3), only 25 of the injury narratives provided information concerning whether or not the seat belt was in use at the time of the incident. Of those cases, 20 indicated that the belt was worn. In five cases, the narrative indicated that the belt was not used. Examining the data set suggests that there were substantial injuries to parts of the body that might have been better protected by more-consistent use of restraint devices.

For off-highway equipment used in mining, the need to protect the operator via operator restraint devices and protection from rollover has been required by regulation[8] since 1969 (Oitto and McLellan 1975). From the author's review of the injury records, there seems to be a lot of variability in the use of seat belts among dozer operators. The reasons for this variability might be further investigated.

Carlson and Hoffman (1981) conducted a series of field studies of improved seat-belt restraint systems involving retractable sheath designs and automatic and manual locking features. The purpose was to design a restraint system that would enhance comfort, fit and convenience. Their prior investigations found that the designs of previously used restraint systems contributed to limited use among equipment operators. A vehicle-sensitive retractor design was chosen, similar to that used in automotive mechanisms. The off-highway equipment systems were set to operate at 0.75 g., which is higher than what was common with automotive designs. The new seat belt design was a combination of commercially available retracting systems, inertial-type locking mechanisms and webbing material. The new designs were field tested at mining sites, and results indicated better acceptance by equipment operators compared to the, then, traditional restraint system design.

The importance of integrating a restraint system with appropriate seat and seat suspension designs was suggested by Appel et al. (1984). They report on the laboratory testing of seat belts, stating that early applications of seat restraints to off-road equipment were similar in design to those used for highway applications (and frontal crashes). This work proved the designs to be less than effective for lateral-impact forces (such as those involved in a rollover). The authors also found that the harness belt did provide for lateral protection, but this type of restraint was cumbersome and restrictive to the operator. The authors argued that a lap belt with lateral shoulder supports would offer a good balance in protection and usability that goes well beyond the previously used lap belts. Appel et al. (1984) also cited the lack of a shock-absorbing seat as the weakest link in the restraint system in 1984.

Sullman (1998) recently studied seat belt usage in the New Zealand logging industry. He found that low use levels were either due to employees forgetting to use the belt, or the annoying design of conventional (rachet-type) seat belts. His study found that seat belt usage was increased by 58% by installing a reminder light and an improved seat belt design.

From the data examined in this study, great variability exists in belt usage, and the reasons for that variability might be investigated[9]. One possible area would be risk perception. For over-the-road vehicles, Calisir and Lehto (1996) looked at factors impacting best usage. They thought that the individual's perception of risk was key.

Tramming direction and speed. Backing up the dozer was an activity associated with many of the jolting and jarring injuries. Out of the 354 vertical jarring incidents, 185 involved the dozer backing up. Backing up is one of those activities that most operators would like to minimize — both in terms of distance and time. Dozer operators may have a tendency to maximize their output (material moved) by minimizing their necessary but unproductive time in backing. Although higher tram speeds in backing up, (generally about 5 mph or 8 km/h) reduces cycle times, such speeds may introduce increased risk by exacerbating the effects of small rises or rocks and provide a low margin of error in perception, judgment and corrective action (slowing down). If operators recognize the hazard, the response might be direct and more reliable in slowing down and maneuvering the dozer through or around the obstacle.

The risk of injury due to twisting and turning in the seat presents a problem. If one accepts that jolts are unexpected, then one solution is for the dozer operators to recognize terrain conditions that are likely to produce high levels of shock. Once identified, the best choice is to slow down or carefully maneuver to avoid the dip, rock or uneven ground. Backing up is a common and necessary task, and if operators are twisting to look behind, then it could expose them to injury due to persistent twisting and turning and the effect of lower level vibrations and shock. By twisting and looking aft, their purpose is to avoid the larger hazards (jolts). If they do not look aft (to maintain a good body posture), then operators become more susceptible to the risk of larger shocks (jolts and jars) due to unseen undulations/obstacles.

Body posture also plays a role in the risk of injury. Some researchers (Bottoms and Barber, 1978) suggest that a poor body posture partially contributes to disorders among agricultural tractor operators. Twisting and turning in the seat (to look behind) is likely to contribute to the frequency and severity of these incidents as it increases the risk of a back injury due to the uneven distribution of the vibrating and shock forces on the spine. Bottoms and Barber suggest that a swivel seat might be appropriate to minimize the awkward postures that can heighten the impact of vibration and shock to the back.

[8] ROPS and seat belts are not required on dozers manufactured before July 1, 1969. See 30 CFR 56.14130 and 30 CFR 77.403(a), "Roll-over protective structures (ROPS) and seat belts."

[9] No recent studies were found that examined seat belt usage among off-highway equipment operators in the US mining industry.

Robinson et al. [1997] gathered WBV data on 11 mining vehicles, three of which included dozers. Their purpose was to profile vehicles and offer recommendations that could help with a planned reintegration of workers who experienced a back injury into other jobs at the mine site. Their goal was to reduce the likelihood of re-injury (due to the cumulative effects of vibration and repeated shocks) by profiling different vehicles and not placing these workers into a vibration- or shock-prone environment. Their results indicated that vibration levels varied considerably across the vehicles tested. Newer equipment tended to fare better. However, a severe mechanical shock level (measured by the maximum crest factor) was recorded for *all* production vehicles[10] monitored. This suggests that severe mechanical shock can occur in any mine vehicle and that ground conditions have a significant role[11].

High-energy, short-duration jolts and jars may also prematurely wear certain components of the dozer. Undercarriage, track maintenance, wear items and repair costs can be highly variable and are estimated at about $27/hour (Hays 1990). These costs might be negatively impacted by jolting and jarring of the dozer. Another item that accelerates wear and contributes to more costly maintenance and repair is high-speed backing (Hays, 1990).

Skilled performance (training). Skilled (safe and productive) performance on a dozer is something that does not come quickly or easily. Blade control takes time. The more sophisticated the dozer control systems, the greater the need to make sure there is a good and reasonable fit between the operator and the technology. Judgment and decision-making are always important in day-to-day operation of off-highway equipment, and the authors argue that this importance increases as the value of the investment increases.

Training can serve to enhance the fit between the technology and how it is used at the job site. Hazard recognition and response skills are an indispensable component of effective (safe and efficient) dozer operation. Hazards can be subtle and hidden. Each of the serious injuries in the data set resulted in a significant social and economic cost, and many of the incidents affected both the dozer and the operator.

From the fatality data (1988 through 1997), five of the victims had two months or less experience on the dozer. For lost-time injuries, dozer operators with less than one year of experience were involved in a sizable number of lost workday incidents. Almost 15% of the lost-time injuries were incurred by operators with less than one year working in the job classification. For fallover and rollover incidents, job experience data were available for 93 incidents. Fourteen out of 93 lost-time incidents occurred to those with less than a year of experience. In contrast, injury victims with one to five years of experience in their job classification were involved in 16 out of 93 fallover and rollover lost-time incidents. The balance (63) had greater than five years of experience on the dozer.

Continuing education for new and experienced dozer operators is fundamental, as the risk of serious injury affects all age and experience groups. Of 116 incidents where the dozer fell over an edge, rolled over or fell into a hidden void, 14 (12%) resulted in fatal injuries. Overall, 80% of the fatalities and 12% of the lost-time injuries occurred while the operator was working near an edge or hidden void or on a steep slope. Thus, the hazards of working near an edge or on a steep slope are especially evident from the analysis of the lost time and fatality data. From the MSHA data, there were no fatalities to dozer operators in 1996 and 1997. But the following three years resulted in ten fatalities to dozer operators while performing common production tasks.

On-the-job training is a common and useful method for teaching and evaluating skills. Skilled performance involves the integration of hazard awareness, recognition and response with dozer operational skills. Across industries, Allen and Nawrocki (2000) suggest that there is a movement back to "training via apprenticeship and on-the-job training experience." They suggest that targeted skills and knowledge will be tied to specific business objectives, that technologies (e.g., multimedia) are available to assist the learner, and that the onus of responsibility will be increasingly on the learner. The authors suggest that these same technologies might also be very useful in assisting the safety/skills trainer to facilitate the instruction, provide up-to-date content, and offer strategies for teaching and evaluating skills. One approach supporting a focus on the skills of the OJT trainer is offered by Semb et al. (2000):

> *"while advances in technology may result in more-sophisticated tools for conducting OJT, the* knowledge and skills of the individual trainer *will always be the* most critical component *of OJT. These include both knowledge of the job and the ability to communicate that job effectively to the on-the-job trainees."*

Semb and his colleagues suggest that the body of literature relating to tutoring might be extended to the OJT environment with the ultimate goal of enhancing the efficiency and effectiveness of the OJT training.

Conclusion

Risk is part and parcel with work life. This analysis finds that further reductions in injury risk require

- more widespread use of seat belts;
- consideration (and maintenance) of the seat and seat suspension systems that might reduce injury risk from jolts and jars;
- research interventions to assess the effect of alternative engineering designs to dampen or isolate the effects of shock and vibration; and
- continued attention to skilled performance, i.e., the integration of hazard awareness, recognition and response with dozer operational skills.

Acknowledgments

The authors would like to thank the employees from Cyprus-AMAX Coal Company's Chinook Mine (Terre Haute, Indiana). Interviews with experienced dozer operators, mine managers and supervisors provided technical information on dozer tasks, training of dozer operators and perspective on the balance of safety and skills training. The collaborative work was performed under a Cooperative Research and Development Agreement (USBM CRADA 6200-0121). We would also like to thank Barbara Fotta, Research Methodologist – NIOSH/PRL, for her review and advice on earlier drafts of this manuscript.

[10] For three dozers in their sample, crest factors (maxBalong the z, or vertical axis) of 12.4, 14.8 and 24 were measured. Threshold limit values specified in ISO 2631 do not accurately reflect the effects of whole body vibration when the crest factors exceed 6.

[11] Of importance, vehicle speed was not reported in this study.

References

Allen, J.A, and Nawrocki, L.H., 2000, "Training in industry," in *Training and Retraining: A Handbook for Business, Industry, Government and the Military*, S. Tobias and J.D. Fletcher, eds., American Psychological Association. p. 261.

Appel, H., Vu-Han, V., and Pirschel, H., 1984, "Occupant protection in earthmoving machines," in *Advances in Belt Restraint Systems: Design, Performance and Usage*, P-84/141, Society of Automotive Engineers, pp. 87-100.

Bottoms, D.J., and Barber, T.S., 1978, "A swiveling seat to improve tractor drivers' posture," *Applied Ergonomics*, Vol. 9, No. 2, pp. 77-84.

Calisir, F., and Lehto, M.R., 1996, "Drivers' risk assessments and their impact on seat belt use," *Proceedings of the 1996 19th International Conference on Computers and Industrial Engineering*, Vol. 31, No. 1/2, pp. 495-498.

Carlson, L.E., and Hoffman, A.G., 1981, "Development of improved seat belt systems for surface mining equipment," Bureau of Mines Open File Report 28-83, contract H0202005, Mobility Systems and Equipment Company, pp. 6-12.

Cross, J., and Walters, M., 1994, "Vibration and jarring as a cause of back injury in the NSW coal mining industry," *Safety Science*, Vol. 17, No. 4, pp. 269-274.

Fotta, B., and Bockosh, G., 2000, "The aging workforce: an emerging issue in the mining industry," *Proceedings of the Thirty-first Annual Institute on Mining Health, Safety and Research*, pp. 33-45.

Gouw, G.J., Rakheja, S., Sankar, S., and Afework, Y., 1990, "Increased comfort and safety of drivers of off-highway vehicles using optimal seat suspension," in *Society of Automotive Engineers Transactions*, Technical Paper 901646, 8 pp.

Griffin, M.J., 1990, "Handbook of human vibration," *Academic Press Ltd.*, pp. 399-404.

Hays, R.M., 1990, "Dozers," in *Surface Mining, 2nd edition*, Kennedy, B.A., ed., Society for Mining, Metallurgy, and Exploration, Inc., pp. 716-723.

May, J.P., 1990, "Analysis of dump-point accidents involving mobile equipment," US Bureau of Mines Information Circular 9250, p. 15.

Miyashita, K., Morioka, I., Tanebe, T., et al., 1992, "Symptoms of construction workers exposed to whole body vibration and local vibration," *International Archives of Occupational and Environmental Health*, Vol. 64, pp. 347-351.

Oitto, R.H., and McLellan, R.R., 1975, "Analysis of fatal accidents involving front-end loaders at metal and nonmetal mines, 1972-1974," Mining Enforcement and Safety Administration, Informational Report 1019, 7pp.

Ranganathan, R., and Mohan, M.V., 1997, "A review of the general effects of whole-body vibration," *International Journal of Vehicle Design, Heavy Vehicles Systems*, Vol. 4, Nos. 2-4, pp. 353-372.

Robinson, D.G., Martin, S.H., Roddan, G., Gibbs, G.H., and Dutnall, J., 1997, "The application of vibration assessment in mining vehicles to return-to-work protocols," *Journal of Low Frequency Noise, Vibration and Active Control*, Vol. 16, No. 2, pp. 73-79.

Semb, G.B, Fitch, M.A, Ellis, J.A, and Kuti, M.B, 2000, "On-the job training: theory, research and practice," in *Training and Retraining: A Handbook for Business, Industry, Government and the Military*, S. Tobias and J.D. Fletcher, eds., American Psychological Association. p. 291.

Sparrell, C.F., 1980, "Off-highway vehicle accidents and operator training," in *Proceedings of the International Off-Highway Meeting and Exposition*, Society of Automotive Engineers, Inc., Technical Paper 800945, 3 pp.

Stanevich, R.L., 1986, "A study of earthmoving and highway construction machinery fatalities and injuries," *Ann. Am. Conf. Gov. Ind. Hyg.*, Vol. 14, pp. 703-710.

Sullman, J.M., 1998, "Increasing seat belt usage in logging machinery," *International Journal of Industrial Ergonomics*, Vol. 21, pp. 397-405.

Turin, F.C., Wiehagen, W.J., Jaspal, J.S., and Mayton, A.G., 2001, "Haulage truck dump-site safety: An examination of reported injuries," NIOSH Information Circular 9454, 29 pp.

Wiehagen, W.J., Mayton, A.G., Jaspal, J.S., and Turin, F.C., 2001, "An analysis of serious injuries to dozer operators in the U.S. mining industry," NIOSH Information Circular 9455, 23 pp.

Zimmermann, C.L., Cook, T.M., and Rosecrance, J.C., 1997, "Work-related musculoskeletal symptoms and injuries among operating engineers: a review and guidelines for improvement," *Appl. Occup. Environ. Hyg.*, Vol. 12, No. 7, pp. 480-484.