A REVIEW OF ACCIDENTS DURING SURFACE MINE MOBILE EQUIPMENT OPERATION

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ABSTRACT

Accidents involving the operation of surface mine mobile equipment were analyzed for the years 1989 through 1991 to determine where safety improvements are needed. This U.S. Bureau of Mines study analyzed a total of 2,852 accidents in metal-nonmetal and coal mining. Haulage trucks accounted for the largest number of accidents, followed by front-end loaders and bulldozers. Haulage truck accidents were also the most severe in terms of lost workdays and fatalities. The number one cause of accidents during operation of the equipment was jarring. Loss of vehicle control was second to jarring in causing accidents, but produced more severe injuries. It is evident that better operator restraints and higher restraint usage rates are needed to reduce accidents and injuries to equipment operators, along with improvements in the shock isolation capabilities of the equipment. These improvements could potentially eliminate or reduce the severity of 60 pct of the equipment operator accidents.

INTRODUCTION

Surface mines account for about 85 pct of the approximately 3.1 billion metric tons of ore extracted yearly from U.S. mines (*1-2*)[1]. One goal of the U.S. Bureau of Mines (USBM) is to reduce the accidents and injuries associated with mining. Mobile equipment related accidents accounted for 12 pct of all surface mining accidents, but 39 pct of the fatalities. The largest portion (40 pct) of these accidents occur to the operator of the equipment.

Past research on mobile equipment accidents has been piecemeal. Oitto and McLellan (*3*) found that many front-end loader fatalities could have been prevented with rollover protective structures (ROPS), seatbelts and adequate training. Haulage truck fatalities in 1973 were found to be caused largely by human error, inattention, and lack of training (*4*). Kenney (*5*) showed that haulage truck accidents were more severe than other mobile equipment accidents. May's analysis of dump-point accidents (*6*)

[1]Italic numbers in parentheses refer to references at the end of this report.

showed that removing material from the base of a stockpile was a frequent cause. Mason (7) found that failure to use seat belts was a factor in 42 pct of the metal-nonmetal (MNM) haulage truck accidents occurring in 1982-84.

The objective of this study was to determine the areas of mobile equipment operator safety in need of improvement. This report covers both coal and MNM surface mining and includes haulage trucks, front-end loaders, scrapers, bulldozers and road graders. The database used in this report includes all accidents reportable to the Mine Safety and Health Administration (MSHA), except contractor accidents. This report is presented to introduce or reinforce awareness in mine safety personnel of the potential hazards associated with mobile mining equipment.

METHOD

The data used in these analyses were gathered from an accident database maintained by the USBM's Spokane Research Center. The Accident Data Analysis (ADA) database uses data collected and managed by MSHA. ADA provides accident statistics and narrative descriptions of reported accidents for the MNM and coal mining industries back to 1975. The accident narratives are those supplied by the mine at the time of the accident. The data base includes only those accidents that are reportable to MSHA, but does not include contractor accidents. The accident data has not been normalized for the amount of miner activity.

Accidents involving the operation of the five pieces of mobile mining equipment were analyzed for the years 1989-1991. A total of 2,852 accidents associated with the operation of surface mine mobile equipment were analyzed. Surface mining was defined as any mine location except underground areas and offices.

ACCIDENT ANALYSIS

Mining Industry

For the years investigated, MNM mines had more accidents, more fatalities, and a higher fatality ratio (percent of accidents which are fatal) than coal mines (see table I). However, coal mine accidents typically resulted in more lost workdays per accident.

Accident Location

About 80 pct of the accidents occurred in surface strip mines, open pits or quarries (see figure 1). Another 13.5 pct of the accidents occurred in preparation plants or mills and 3.6 pct at surface locations of underground mines. The "remainder" portion in figure 1 includes dredge mining, independent shops and yards, culm bank or refuse areas, and surface coal auger mining.

Type of Equipment

The number of accidents and the mean number of lost workdays for each type of equipment is shown in table II. Haulage trucks,

Table I. Accident severity by industry

Industry	Number	Mean LWD	Days Off Pct	No-Time-Lost Pct	Fatalites	
					Number	Ratio[1]
MNM	1,744	14.9	54.9	26.8	32	1.8
Coal	1,108	23.8	68.1	20.0	15	1.4
Total	2,852	18.4	60.0	24.2	47	1.6

LWD Lost workday.

[1]Percentage of accidents resulting in fatalities.

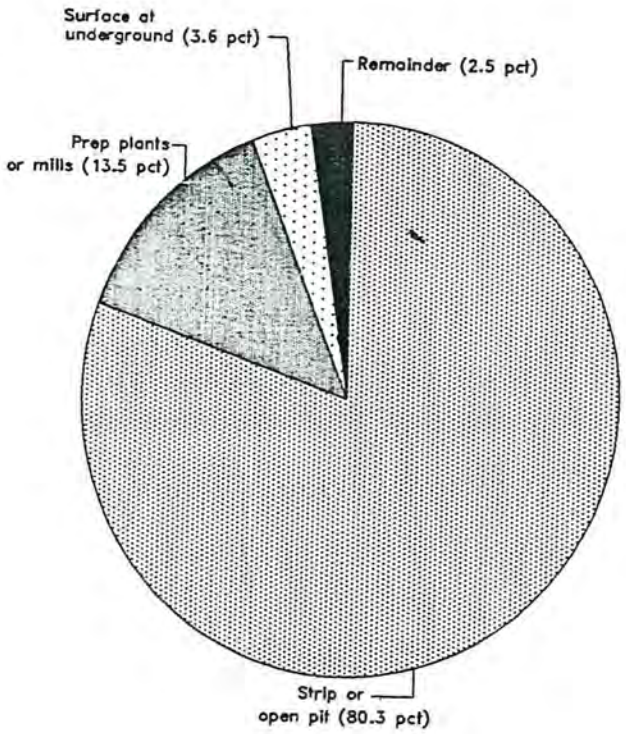

Figure 1. Surface mine mobile equipment operation accidents by location.

loaders and dozers combined, accounted for 91.9 pct of the accidents while scrapers and graders accounted for 8.1 pct. Haulage truck accident severity, as measured by the mean number of lost workdays, was highest. The fatality ratio (percentage of accidents resulting in fatalities) for haulage trucks was higher than the other equipment except road graders. A closer look at the 47 fatalities shows that haulage trucks were responsible for 60 pct and front-end loaders 21 pct (table II). The three remaining pieces of equipment totaled 19 pct of the fatalities.

The number of accidents associated with each piece of equipment varied widely between coal and MNM mining. Figure 2 shows that haulage trucks were the largest portion of both coal and MNM mining accidents. In coal mining accidents, dozers were the second most frequent, while front-end loaders were second in MNM mining. Scraper accidents were also more prevalent in coal mining than in MNM mining, probably because of the increased use of scrapers in coal as compared to MNM mining.

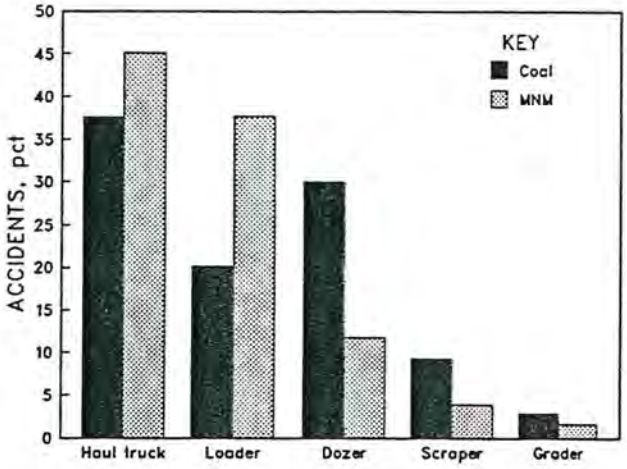

Figure 2. Accidents by equipment type and industry.

Table II. Accident frequency and severity by equipment type

	Accidents		Fatalities			Mean
Equipment	Number	Pct	Number	Pct	Ratio[1]	LWD
Haulage Trucks	1,203	42.2	28	60	2.3	19.2
Front-end loaders	881	30.9	10	21	1.1	18.6
Bulldozers	537	18.8	5	11	0.9	19.0
Scrapers	171	6.0	2	4	1.2	12.3
Road graders	60	2.1	2	4	3.3	11.5
Total	2,852	100.0	47	100	1.6	18.4

LWD Lost workday.

[1]Percentage of accidents resulting in fatalities.

Fatalities

Loss of control accidents were responsible for 29 of 47 fatalities (table III). Loss of control fatalities most frequently involved haulage trucks falling down a slope and many of these occurred while the truck was dumping. Sixteen of the 29 loss of control fatalities involved a rollover of the vehicle and twelve involved the operator jumping or getting thrown from the vehicle. Collisions were the second most common cause of fatalities. Nine of the twelve fatal collisions were a pedestrian getting struck by a vehicle.

Table III. Brief description of fatalities

Accident Description	Fatals
Loss of control:	
Truck dumping	10
Truck tramming	5
Truck parked, runaway	1
Front-end loader	6
Bulldozer	4
Road grader	2
Scraper	1
Collision:	
Vehicle struck pedestrian	9
Vehicle to vehicle	3
Pedestrian hit by flying object	2
Natural causes, heart attack	2
Passenger fell out of loader	1
Burn, propane fire	1
Total fatalities	47

Job Experience

Figure 3 shows the distribution of accidents by job experience of the accident victim. The graph shows that 31 pct of the accidents occurred to operators with one year or less of experience at performing that job. Another 11 pct of the accidents were charged to personnel with just one to two years experience.

One may wonder whether the high number of inexperienced accident victims indicates that inexperienced miners are more prone to accidents, or is it because there are more inexperienced workers in the mining work force? To answer this we compared the accident data with Butani and Bartholomew's (*8-9*) estimates of the demographics of the mining work force of 1986 (table IV). The demographics data shows that indeed there are more equipment operators with one year or less of job experience than for any other one year period. But this figure of 19.3 pct is eclipsed by the 31.1 pct of the accident data. Thus, both factors of our question appear to play a role in the high percentage of inexperienced accident victims.

Figure 3. Job experience distribution of equipment operation accident victims.

Injuries

The types of injuries that result from mobile equipment accidents vary, but sprains and strains were far and away the largest category of injuries, with 42 pct. This was the leading type of injury for all five types of equipment, in both coal and MNM mining. Sprain or strain injuries

Table IV. Comparison of job experience from 1986 demographics with 1989-91 accident data

Job Experience (Years)	1986 Demographics[1] (Pct)	1989-91 Accidents (Pct)
>0 to ≥1	19.3	31.1
>1 to ≥2	14.3	10.9
>2 to ≥3	10.5	8.0
>3 to ≥5	14.2	10.9
>5 to ≥10	23.2	15.0
>10 to ≥20	14.1	18.7
>20	4.4	5.3

[1]From Butani and Bartholomew (*8-9*).

averaged 19.4 lost workdays. Sprains and strains were followed by multiple injuries, bruises, lacerations, and fractures. Fracture injuries were among the most severe, averaging 33.1 lost workdays. Injuries to the back were most frequent, accounting for 29.8 pct of the accidents. Back injuries tended to be more severe (22.2 lost workdays) than the average injury for all accidents (18.4 days). Multiple body part injuries were the second most common and one of the most severe, averaging 28.1 lost workdays. Other frequently injured body parts were the neck, eyes, fingers, head and shoulders.

Accident Classifications

The accidents were classified by the action, event, or cause which best describes the circumstances of the accident. Table V shows the major classifications, the percentage, and the mean number of lost workdays for each type. The number one cause (34.5 pct) of accidents was jarring of the equipment operator. These happened in different ways, but all involved an acute trauma event which jarred or jolted the operator during otherwise normal operation. Back and neck strains or sprains were the most frequent injuries. Jarring does not include any unusual events such as rollovers, runaways (loss of control), collisions, or cumulative trauma injuries from prolonged exposure to equipment vibrations (passive strain).

The most common cause of jarring accidents (17.1 pct of the total) was rough ground (table V). These accidents resulted from the vehicle hitting bumps, rocks, potholes, etc in their path and occurred at the highest rates with scrapers. Loading shocks occurred when a haul truck operator was jarred from a boulder dropped into the truck bed or when a loader or shovel bucket struck the truck body. Jarring of the cutting edge typically occurred when a loader bucket or dozer blade struck a buried boulder or concrete apron.

Table V. Classifications of accidents related to equipment operation

Accident Classification	Number	Pct	Mean LWD
Jarring:			
Rough ground	490	17.1	17.3
Loading shock (trucks)	142	5.0	21.4
Cutting edge jarred	116	4.1	19.7
Unspecified	80	2.8	27.6
Dumping shock (trucks)	52	1.8	31.2
All others	103	3.6	11.9
Total jarring	983	34.5	19.2
Loss of control:			
Too close to edge	189	6.6	26.8
Runaway	133	4.7	27.6
Unknown conditions	76	2.7	16.3
All others	74	2.6	20.2
Total loss of control	472	16.5	24.3
Passive strain	322	11.3	19.4
Collision:			
Vehicle to vehicle	105	3.7	23.7
Vehicle to pedestrian	77	2.7	18.1
Vehicle to stationary object	52	1.8	15.5
Total collisions	234	8.2	20.0
Being struck by flying-falling object	139	4.5	14.5
Debris in eye	130	4.6	1.2
Getting caught or smashed	108	3.8	15.7
Striking against equipment	57	2.0	14.0
Highwall collapse or rock fall	54	1.9	20.4
Overexertion	53	1.9	21.8
Fire	51	1.8	5.2
All others	249	8.7	15.4
Grand total	2,852	100	18.4

LWD Lost workday.

Loss of control accidents totaled 16.5 pct of all accidents (table V). Loss of control accidents were defined as resulting in the vehicle traveling

under little or no control from the operator. Two classifications describe two-thirds of the loss of control accidents: 1) getting the vehicle too close to the edge of a slope or road and 2) runaway vehicles caused by mechanical problems. Injuries from these accidents were among the most severe, with multiple injuries most common. Getting too close to a slope edge often caused the vehicle to fall down the slope and roll over. Many of these accidents occurred with haulage trucks while dumping. A vehicle too close to the edge of a slope may result in a slope failure or the vehicle going through or over the berm. Runaways were defined as any out of control incident resulting from mechanical problems, including operator errors causing the vehicle to stall. Runaways typically happened with the machine tramming a roadway, frequently at higher speeds than most "too close to edge" accidents. This may explain the higher number of lost workdays for runaway accidents.

The third most frequent category of accidents was passive strains. These 322 accidents (table V) resulted from equipment operators being subjected to repeated shocks and vibrations from normal equipment operation. These were often similar to the rough ground jarring accidents, except no single incident was cited as causing the injury. The injuries were predominately back and neck strains or sprains and averaged 19.4 lost workdays.

Collisions were the fourth most common type of accident, accounting for 8.2 pct of the total (table V). Collisions were classified as three different types, listed in order of the number of accidents: vehicle to vehicle, vehicle hitting pedestrian, and vehicle striking a stationary object. Vehicle to vehicle collisions were the most severe in terms of mean lost workdays. The most frequent injuries for all types of collisions were sprains or strains and multiple injuries to the back or multiple body parts. The remaining major accident classifications are listed in table V.

A total of 1,668 accidents involved an acute impact to the equipment operator. These accidents include all of those in the jarring, loss of control and collision classifications (not including pedestrian collisions) plus others from the highwall collapse and all others categories (table V). These acute impact incidences represent over 60 pct of the accidents occurring to the operators. Many of the passive strain accidents may also have involved acute impacts, but were not included in this total. Many of the injuries from acute impact accidents could be eliminated or their severity reduced by better operator restraints or improved isolation from the severe impacts which tend to cause injuries.

Table VI. Principal direction of force by equipment type

Equipment	Principal Direction of Force							
	Rollover		Longitudinal		Lateral		Vertical	
	Number	Pct[1]	Number	Pct[1]	Number	Pct[1]	Number	Pct[1]
Haulage trucks	191	34	112	20	64	11	193	34
Front-end loaders	40	15	128	47	19	7	84	31
Bulldozers	29	13	65	30	9	4	115	53
Scrapers	10	11	20	22	9	10	50	56
Graders	2	6	18	58	1	3	10	32
Total	27	23	343	29	102	9	452	39
Average LWD's	22	-	18	-	32	-	17	-

LWD Lost workday.
[1]Percent of row total.

Table VII. Principal direction of force for selected acute impact accidents

Accident Type	Principal Direction of Force							
	Rollover		Longitudinal		Lateral		Vertical	
	Number	Pct[1]	Number	Pct[1]	Number	Pct[1]	Number	Pct[1]
Rough ground	2	0.5	36	9	17	4	328	86
Cutting edge jarred	0	0	79	80	3	3	17	17
Loss of control	248	78	48	15	15	5	5	2
Collision	2	2	95	85	15	13	0	0
Dumping shock	13	30	2	5	1	2	28	64
Loading Shock	1	1	11	15	35	47	27	36

[1]Percent of row total.

Principal Direction of Force

The principal direction of force (PDOF) was estimated for 71 pct of the accidents involving acute shock forces to the operator (1,169/1,668). PDOF is the predominate direction or axis of the forces which were most responsible for causing injuries. The PDOF was determined from the accident narrative. For accidents in which the PDOF could be determined, 39 pct of the accidents involved vertical forces, 29 pct longitudinal (forward and backward) forces, 23 pct were rollovers and 9 pct lateral forces (table VI). The percentages for the different types of equipment varied. For instance, rollovers varied from 6 pct of grader accidents to 34 pct of haul truck accidents. The largest concentration of force direction was for road graders, where 58 pct of the accidents were longitudinal forces (table VI). Haulage trucks, dozers and scrapers all had vertical forces as the most frequent direction of force. Loader and grader accidents most frequently resulted from longitudinal forces.

The last row of table VI shows that the most severe injuries occurred with a lateral PDOF. This was probably because seat belts provide the least amount of protection in this direction (*10*). Lateral collisions averaged 43 lost workdays while longitudinal collisions averaged 16 lost workdays. The least severe accidents occurred with vertical forces, having an average of 17 lost workdays.

The PDOF for rough ground accidents was vertical in 86 pct of the cases for which a PDOF could be determined (table VII). Jarring of the cutting edge and collision accidents were predominately longitudinal. Truck dumping shocks were mostly vertical, while loading shocks were lateral or vertical. The majority (93 pct) of the rollovers occur from loss of control accidents. Nearly 80 pct of the loss of control accidents, in which the PDOF was determined, were rollovers (table VII). It is noted that at least 50 pct of all loss of control accidents result in rollovers. Injuries from rollover accidents averaged 22 lost workdays.

Seat Belt Usage

Seat belt usage was determined for 163 of the 2,720 accidents involving an equipment operator (most accident reports do not mention seat belt usage). Seat belts were worn in 89 accidents and not worn in 74 accidents (table VIII). Due to the small number of cases for which seat belt usage was determined, firm conclusions could not be made, but the following trends emerged. When seat belts were worn, the lost time accidents averaged 31 lost workdays and no fatalities occurred. When belts were not worn, eight fatalities occurred and the lost time accidents averaged 41 lost workdays. Also, 25 pct of the accidents resulted in no-time-lost when seat belts were used, compared to 7 pct when belts were not worn. The lost workday figures

Table VIII. Seat belt usage and its effect on accident severity

Accidents with seat belt use determined	Seat Belts			
	Worn		Not worn	
	Number	Pct	Number	Pct
Total	89	100	74	100
Lost workdays	61	69	54	73
Average lost workdays	31	-	41	-
No-time-lost	22	25	5	7
Restricted work	6	7	4	5
Fatalities	0	0	8	11
All Others	0	0	3	4

mentioned in this paragraph are probably higher than most accidents because seat belt usage is usually determined for only the more severe accidents, thus skewing the lost workday figures upwards.

The difference between wearing and not wearing a seat belt is magnified for the loss of control accidents. Loss of control accidents with a rollover averaged 18 lost workdays when a seat belt was used, with no fatalities. When not wearing a seat belt, the lost work time jumped to 44 days and 4 fatalities occurred. When the operator was thrown out of the vehicle, the lost work time averaged 55 days and 6 fatalities occurred. When the operator jumped from the machine, the average was 36 lost workdays and four fatalities occurred.

DISCUSSION AND SUMMARY

Every year surface mine mobile equipment are involved in a significant portion of our nation's mining accidents, particularly severe accidents. Most of the accidents were concentrated in a few areas, allowing safety improvement efforts to be more focused.

The high number of haulage truck accidents was probably due to the large number of haulage trucks used in the industry. Many surface mines are dependant on truck haulage as the primary means of hauling ore and waste. Front-end loaders were involved in the second highest number of accidents overall, but were more frequent in MNM mining than in coal. Bulldozer accidents (third overall) were much more frequent in coal than in MNM. Dozers are typically utilized more in coal mining, where they do additional tasks such as removing overburden and spoil, ripping coal, and reclamation activities. Scrapers and road grader accidents were less frequent, but occurred more often in coal mining than in MNM mining.

Although fewer accidents were reported in coal mining than in MNM mining, they were more severe on average. Coal mine accidents had a higher average number of lost workdays and fewer accidents with no-time-lost than MNM mining. Thus, coal mine accidents more frequently resulted in lost work time, and tended to be more severe in terms of the injury recovery time. However, coal mining had a lower fatality ratio than MNM mining.

Haulage trucks and road graders had fatality ratios higher than the other equipment. The high ratio of haul truck fatalities was probably due to the size and speed of the trucks compared to the other equipment. Trucks tramming on haul roads may reach speeds in excess of 56 km/h (35 mph). Most of the haulage truck fatalities were from loss of control accidents, either at dump points or while tramming haul roads. Many of these accidents result in rollovers and also operators jumping or being thrown from the vehicle. The

fact that the most frequent equipment accidents, those involving haulage trucks, are also among the most deadly helps to explain why mobile equipment accidents as a whole are more severe than many other surface mining accidents.

The high fatality ratio of haulage truck accidents is contrasted with the low fatality ratio of dozers, lower than all the other equipment. This may be due to the slower operating speeds and greater stability typical of dozers, particularly crawler dozers. Even though dozer accidents result in fewer fatalities, they are none the less one of the most severe in terms of lost workdays. The longer recovery time for dozer accident injuries could be the result of the rougher and steeper terrain on which dozers are operated and the poor isolation of dozer operators from ground induced vibrations. This could lead to more severe rough ground and loss of control accidents.

Over 60 pct of the fatal accidents were from loss of control of the vehicle. These accidents were most frequent with haulage trucks, particularly while the truck was dumping. Over 80 pct of the fatal loss of control accidents involved some combination of a rollover or the operator jumping or getting thrown out of the vehicle. These statistics point to the importance of wearing a seat belt and staying within the cab's ROPS.

The other large portion of fatal accidents was pedestrians being struck by a vehicle (9 of 47 fatalities). Seven of these occurred with haulage trucks, which typically have larger blind areas than other machines. Miner training needs to emphasize the poor visibility of objects near mobile equipment, particularly haul trucks. It's a good idea to demonstrate to all mine personnel the extent of the blind areas around the equipment.

Loss of vehicle control accidents were the most severe in terms of average lost workdays and fatalities. However, the accident statistics showed that this was not true if seat belts were worn by equipment operators. Not wearing a seat belt more than doubled the lost workdays for rollover accidents compared to similar accidents with seat belts worn. Loss of control accidents were most severe, in terms of lost workdays and fatalities, when the operator was thrown out of the vehicle. In an emergency or accident situation, it is almost always better to stay in the cab with the seat belt on, rather than trying to jump clear of the vehicle and risk being run over by the machine. The operators who were successful in jumping clear of the vehicle still had more severe injuries than those who rode it out with their belts on.

Seven percent of the accidents without the use of a seat belt resulted in no-time-lost from work, while 25 pct produced no-time-lost when seat belts were worn. Perhaps the most important reason for wearing a seat belt is saving lives. No fatalities occurred with the operator wearing a seat belt, however eight fatalities happened when belts were not used. Over 60 pct of the equipment operator accidents, those involving acute impacts, could potentially be eliminated or their severity reduced by improved seats and operator restraints.

The distribution of accident victim job experience showed that the percentage of accidents decreases with increasing job experience. A comparison with a 1986 miner demographics study (*8-9*) indicated that two factors account for the high number of inexperienced accident victims. First, there tend to be a lot of inexperienced workers operating mobile equipment. Secondly, inexperience on the job may be contributing to a higher incidence of accidents. Additional training for new equipment operators or refocused training emphasis should be considered at all mines. Equipment operators need to exercise extra care when working in conditions shown to contribute to many of the accidents, such as rough ground, near slope edges, and while loading trucks or loader buckets.

Back sprains and strains were found to be the most common injury. Fitness programs supported by the mine may reduce the costs associated with back injuries. An operator's seat

that fits properly and has good shock and vibration attenuation capabilities may prevent many of the jarring or passive strain injuries. A person tightly coupled to the seat with a properly worn seat belt is more likely to escape injury in the event of an accident (*11*). Upper body restraints in addition to the standard lap belt provides additional restraint. Upper body motion during sudden vehicle movements contributes to back and neck strains, sprains or twisting.

The principal direction of force data provided in this report gives additional information on the importance of improved operator restraint. Standard lap belts are most effective for forces applied in the vertical direction. Even though the largest percentage of accidents involved primarily vertical forces, about 60 pct of the accidents involve other motions. Restraint of the upper body by shoulder belts may reduce injuries associated with nonvertical forces and rollovers.

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