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Maintenance and repair injuries in US mining

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Abstract

Purpose ––The purpose of this paper is to identify key tasks, tools, and equipment associated with maintenance and repair injuries at US mines and to provide some mitigation strategies to reduce these types of injuries.

Design/methodology/approach ––This study analyzed incidents resulting in injuries reported to the US Mine Safety and Health Administration from 2002 to 2011. Incident reports were limited to those occurring at mining plants, shops, yards, and aboveground locations. Incident reports were analyzed to determine which activities contributed to injuries and were due to machine maintenance and repair, non-powered hand tools, and powered hand tools. An in-depth analysis of the root causes of these injuries was then performed.

Findings ––Maintenance and repair in mining is associated with a significant number of hand and finger injuries with a range of severities and averaging over 20 amputated fingers, 180 fractured hands and fingers, and 455 hand and finger lacerations per year. Many of these injuries are caused by hands being struck by or caught in tools and equipment. Back and shoulder strains are found to be associated with the most days lost from work and are mostly attributed to materials handling.

Practical implications ––Occupational injuries and fatalities still occur with high incidences in the mining sector. The mission of the Office of Mine Safety and Health Research (OMSHR; part of the National Institute for Occupational Safety and Health, NIOSH) is to “eliminate mining fatalities, injuries, and illnesses through research and prevention.” As part of this work, OMSHR acquires surveillance data from MSHA to quantify the types and sources of injuries at US mining facilities. The authors evaluated maintenance- and repair-related injuries at US mining sites (excluding underground coal mines). Results of this study suggest a need for improved design of machine guarding, improved hand protection through gloves and equipment design/redesign, and manual materials handling solutions.

Originality/value ––The findings indicate that maintenance and repair in mining include occupational risks that may be managed through modifications to machines, proper usage of hand tools and hand protection, and improved manual materials handling processes.

Keywords

Mining; Hand tools; Maintenance and repair; Occupational health and safety

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I. Introduction

Plant and equipment maintenance and repair tasks have long posed challenges ranging from human performance issues leading to acute traumatic injuries and fatalities (Cawley, 2003; Lind, 2008; Lind and Nenonen, 2008), reduced equipment availability during troubleshooting and repair, and equipment failure due to errors during maintenance. Not only is this work non-routine, there are, among other issues, machine and electrical hazards, materials handling exposures, falls, access issues that restrict posture and increase biomechanical demands, and injuries associated with hand tools. In published research, these problems have been approached from several viewpoints including engineering (Harring and Greenman, 1965; Unger and Conway, 1994), human error and ergonomics (Dhillon and Liu, 2006; Koli et al., 1998; Mason, 1990), and risk assessment (Lind et al., 2008).

In a study of fatal or severe injuries sustained during plant maintenance, Lind (2008) found that 48 percent of 33 fatalities studied occurred during planned preventive operations. For fatalities, the leading causes were being crushed or caught between (27 percent) and falls (27 percent). For severe non-fatal injuries, the leading causes were being crushed or caught between (39 percent) and jumping or falling (21 percent). In addition to falls and traumatic injuries from incursions with machinery or parts, maintenance tasks in aviation maintenance were found to pose ergonomics deficiencies including frequent awkward and restricted postures, working in hot and noisy environments, forceful exertions, and manual materials handling (Chervak and Drury, 1996). To address these latter exposures, Koli et al. (1998) developed an ergonomics audit as an approach to assess human-system mismatches in aviation maintenance.

From an ergonomics standpoint, addressing the issues associated with maintenance and repair activities is difficult due to the variable nature of the work, the changing location of the tasks, and the inherent complexity of accessing, diagnosing, and repairing various types of equipment. These complexities may partly explain why there has been comparatively little ergonomics research addressing maintenance. Mining facilities such as plants, shops, and yards include a class of maintenance activities amenable to more detailed ergonomics research. Although the specific equipment and processes vary by mineral, almost all plants use similar types of equipment requiring routine maintenance work, and many of these pose unique maintenance challenges including safety and health exposures.

As required under Code of Federal Regulations Title 30Part 50 Section 50.20, mine operators and contractors must file a Mine Accident, Injury, and Illness Report (Mine Safety and Health Administration (MSHA) Form 7000-1) for all reportable accidents, injuries, or illnesses incurred at US mining facilities. Reportable occupational injuries include all incidents that require medical treatment or result in death, loss of consciousness, inability to perform all job duties on any workday after the injury, or temporary assignment or transfer to another job. First-aid-only injuries are not reportable provided there are no lost workdays, restricted work activity, or transfer because of the injury. Reportable occupational illnesses include any illness or disease of a miner that may have resulted from work at a mine or for which award compensation is made. These data are in the public domain, and are provided in statistical analysis software format (IBM SPSS, Somers, NY) by the National Institute for Occupational Safety and Health (www.cdc.gov/niosh/mining/data/). These are the most comprehensive publicly available data the authors are aware of, and formed the basis for this study.

Previous research has examined severe, fatal injuries associated with plant maintenance. Many neglect the less severe injuries and those injuries without days lost from work which are likely preventable and have the potential to be as costly as more severe injuries. One study (Tierney, 1977) was found that examined maintenance and repair activities in metal and non-metal mines. The author asserted that maintenance workers are most likely to get hurt if the equipment has an excessive number of pinch points, hazards are increased when the worker has to apply force and recommended the increased usage of power tools as well as improved welding methods. Significant injury causes were determined from a relative hazard index which was based on an estimated amount of time spent performing a specific task compared to the occurrence of injuries during these tasks during 1974. However, this hazard index did not account for accident severity and the time values may not have been representative of the actual task.

To the authors’ knowledge, this is the first study to examine accident reports submitted to the MSHA caused by maintenance and repair work including fatal accidents as well as those incidents with and without days lost from work for a ten-year time period. The specific goals of this analysis were to:

- determine the most frequently cited causes of maintenance and repair injuries at US mining facilities;
- identify key tasks, tools, and equipment associated with injuries; and
- recommend remedies to reduce these types of injuries.

II. Methods

Mine accident, injury, and illness reports

Due to the wide variety of injuries in mining, accident, injury, and illness reports from the MSHA were obtained for the most recent ten-year period (calendar years 2002-2011). This data were evaluated to determine the most frequently cited causes of maintenance- and repair-related injuries in mining. Incidents where the worker was thought to be performing maintenance or repair tasks were selected. These incidents were those where the worker activity at the time of injury was coded as machine maintenance and repair, non-powered hand tools, or powered hand tools. Next, the data set was further filtered to include surface facilities, plants, shops, and yards. The most prevalent injury classifications were identified, and data were further filtered to include only these injury classifications. The final data set included maintenance- and repair-related activities occurring at mining plants, shops, and yards where the incident was due to hand tools, handling material, machinery, or slip/trip/fall (STF). A total of 21,799 incidents reported to MSHA were acquired and imported into statistical analysis software (IBM SPSS) for further analysis. Analyses were performed to ascertain which activities would benefit from further research to reduce risks for injury. Injury narratives were also read to determine if specific equipment or conditions could be linked to the incidents. The days lost from work were also investigated. In this analysis, the days lost per incident is the sum of the actual days lost from work and any days of restricted work activities.

Similar types of injuries were grouped together for analysis. Injuries resulting from an employee striking or being struck by an object were combined into the “struck by” category. Injuries due to an employee being caught in, under, or between an object or objects were grouped into the “caught in” category.

III. Results

The final data set included 21,799 incident reports including 37 occupational fatalities, 12,250 non-fatal incidents with days lost from work, 9,322 incidents with no days lost from work, and 190 unknown cases. Table I shows the count and percentages of incidents and distribution of lost workdays by accident classification. Incidents where the employee slipped, tripped, or fell were associated with the highest median days lost from work, and handling material was associated with the highest cumulative days lost from work.

Handling materials

The one fatality from handling materials occurred when a conveyor roller fell off a catwalk and onto a worker at ground level. The 131 partial or total disabilities are made up of one shoulder dislocation, 25 hernias, and 105 amputations (101 finger(s), two toe(s), one hand, and one foot). The causes of the amputations were found to be: 41 severed, 21 crushed, 18 caught between/pinched/struck by, 13 described only as amputation, three pulled off, and eight were not described. The causes of these amputations included 53 cases where an object moved unexpectedly, in 23 cases the worker did not move out of the way of a moving object, and 18 involved a machine that was running or was turned on during maintenance.

Lost workday incidents were primarily caused by workers being struck by, caught in, and over-exerting themselves while handling objects such as metal covers and guards (19 percent) and other types of metal objects (26 percent). These injuries tended to affect the fingers with most injuries being bruised, crushed, lacerated, or fractured fingers (20 percent), along with several back (17 percent) and shoulder (6 percent) strains.

Incidents with no days lost include struck by and caught in metal covers and guards, other metal objects, and pulverized minerals causing lacerated and fractured fingers and hands (22 percent) and eye lacerations, abrasions, and dust-related irritations (10 percent). These incidents also included several bruised, crushed, lacerated, or fractured fingers (23 percent) caused by belt conveyors, metal covers and guards, and other metal objects and chemical eye burns (4 percent) from absorption of lime, cleaning solutions, and other chemicals.

Non-powered hand tool

The three fatalities in this area occurred when the employees were working on equipment and there was an unexpected motion that was not blocked. One case involved a jack, and the other two cases occurred when removing bolts from equipment. The 57 partial or total disabilities are made up of one laceration, 15 hernias, and 41amputations (39 finger(s), one lower leg, and one foot). The causes of the amputations were found to be as follows: 11 severed, ten crushed, nine pinched, and five described only as amputation. The hernias occurred when using pry bars and four of the disabilities were associated with the use of come-a-longs which failed or slipped.

Lost workday incidents were associated with the use of axes and hammers (21 percent), crow and pry bars (15 percent), wrenches (14 percent), and knives (7 percent). Almost one-third of these injuries were caused by an employee being struck by a hand tool and resulted in bruised, lacerated, or fractured hands and fingers with a median of eight days lost from work. Another third of the lost workday incidents were due to employees over-exerting themselves while using hand tools. These injuries had a median of 18 days lost from work. Most injuries were back and shoulder strains from using axes and hammers, crow and pry bars, and wrenches. Nine percent of these incidents were finger injuries caused by workers getting their fingers caught in tools and parts when performing maintenance and repair. Incidents without days lost from work were mostly lacerations to the fingers (26 percent), hands (10 percent), and thigh (5 percent), and fractured fingers (8 percent).

Powered tools and machinery

Of the 24 fatalities in this category, five occurred while working on mobile equipment (bucket loader, bulldozer), and four involved a crusher. Three victims were hit by a falling tree while tree cutting. Five deaths can be attributed to not blocking equipment while working on it and three can be attributed to failure to lockout/tagout equipment. Three victims were contacted by high-pressure liquid (water from power washer and diesel fuel) and three were killed while cleaning out pipes or tanks. In many of the disabling injuries, workers were repairing moving equipment resulting in finger amputations. A total of 41 of the disabling injuries were associated with running equipment and 16 were attributed to cleaning or clearing blockage. There were also three hernias associated with drills or impact wrenches, one eye laceration, one enucleation, one crushed hand, and two amputated hands.

Most injuries with days lost were caused by workers being struck by powered and rock drills (27 percent), over-exerting themselves while using powered and rock drills (17 percent), getting caught in machine parts and metal covers and guards (10 percent), and getting struck by metal and equipment parts (8 percent). The primary injuries were bruised, fractured, and lacerated hand and fingers (30 percent), and back strains (7 percent).

Injuries not resulting in days lost from work were mostly lacerations and fractures of the hands and fingers (37 percent) due to getting struck by powered tools, machine parts, and other forms of metal equipment and parts. Several eye injuries such as lacerations and dust in the eyes (26 percent) were associated with flying debris and pulverized minerals.

STF

The nine fatalities in this category occurred during a variety of maintenance tasks. All of these incidents were falls from heights and two were from a roof. One fatality was attributed to failure to lockout and tagout. All nine victims were not wearing fall protection. Five STF cases were classified as permanent or partial disability. Four of the cases appear to be falls (two losses of balance and two surfaces gave away) and one involved a trip. These incidents resulted in two finger amputations, two back fractures, and one shoulder dislocation.

Lost workday incidents were predominantly sprains or strains of the knees (12 percent), back (8 percent), ankle (6 percent), and shoulder (5 percent). Several incidents also resulted in injuries to multiple parts (12 percent). In most cases, the worker was injured by falling to the ground (41 percent) or to walking surfaces (16 percent), or when falling onto metal covers and guards (7 percent) and surface mining machines (7 percent). Most STF incidents resulted in days lost from work. Other incidents caused lacerations (31 percent) to the head, hand, fingers, and knees, and sprains and strains (26 percent) to the back, knees, and ankles, which did not incur any lost workdays.

Injury sources

The sources of injury were analyzed to determine which categories were associated with the greatest number of days lost from work. A tree diagram showing the sources of injury, type of injury, and body part affected is shown in Figure 1. Overall, metal objects such as pipes, wires, and machine parts were associated with the greatest number of days lost from work causing struck by, over-exertion, and caught in injuries.

The number of days lost by type of injury was also examined. Results showed that the greatest number of days lost due to a specific type of injury were associated with back and shoulder strains followed by fractures and lacerations of the hands and fingers. Overall, sprains and strains accounted for 42 percent of all the days lost

IV. Discussion

This paper examined all reportable incidents resulting in injury due to maintenance and repair activities at US surface mining sites and plants. The aim of this research was to determine the key types of injuries occurring in these operations with hopes of providing practical recommendations to enhance miner safety or identify areas where more research is needed. This paper presented the types of injuries, associated activities, and types of equipment that resulted in the largest percentage of injuries based on injury classifications. The methods included analyzing the incident data reported to MSHA along with fatal accident reports generated by MSHA.

A novel element of this approach was the inclusion of all severity levels of accidents. Many analyses choose to focus on fatal accidents or those resulting in days lost from work. By focussing on the severe injuries, one may lose site of the frequent injuries which may have had potential to become severe in other circumstances. From an organizational standpoint, encouraging the reporting of those less severe accidents and near misses may help to proactively identify and correcting accident pathways, improving safety culture (Reason, 1998). While, this paper was not intended to research the cultural side of safety, it is evident that similar types of injury causes were found for severe and less severe hand and finger injuries which may point to a need for more organizational learning on the prevention of hand injuries during maintenance and repair.

Manual materials handling causes injuries in all industries and was responsible for 36 percent of all maintenance- and repair-related injuries and days lost from work. This included not only loading and unloading supplies, but also handling materials as part of performing machine maintenance and repair. Although not the most frequently cited injury type, back and shoulder strains contributed to a considerable portion of the days lost from work. Involving increased injury severity and recovery time, these injuries place a significant burden on company finances.

Transporting equipment and parts to maintenance and repair locations can be a daunting and physically exerting task when lift-assist devices are not readily available. Manual hoisting equipment (such as a come-a-longs or chain pulls) are commonly used but require significant effort along with repetitive, forceful pulling. Properly placed tools and supply storage can reduce the amount of tools workers carry and facilitate the use of the proper tool for the job, thereby reducing materials handling as well as hand tool injuries. Designing or modifying plants to include hoists or cranes can eliminate the need for manually handling heavy or awkward equipment. However, with the addition of these systems, consideration must be taken to ensure that most equipment can be accessed.

In mines and plants, maintenance and repair is widely accepted as dynamic, non-repetitive, and physically demanding work requiring frequent walking between job sites. With the high volume of time spent inspecting belts and travelling to and from maintenance and repair locations, the high percentage of STF injuries was expected. There may be many contributing factors to these injuries such as environmental factors, obstructed walkways due to poor housekeeping or improper maintenance of equipment, obstructed view while carrying objects, poor walkway design, or overall poor plant design. Many plants are located outside where environmental factors may cause treacherous walking conditions including ice, mud, and uneven ground.

Although accounting for only 11 percent of the incidents, STFs were associated with 21 percent of the days lost from work. This indicates a higher level of injury severity than the other accident classifications. Many STF accidents may be prevented through engineering and administrative controls. Improved lighting systems may allow workers to easily identify and avoid potential hazards. Rigorous housekeeping procedures (e.g. clearing debris and cleaning spills frequently and regular walkway inspections to track walkway integrity may reduce the potential hazards associated with improperly maintaining walkways. The friction afforded by a walkway material deteriorates over time and use. Burnfield and Powers reported an 81 percent chance of slipping when the coefficient of friction provided by a level walking surface was 0.153 and a 6 percent chance of slipping when this friction was increased to 0.308. Just as tire treads wear reducing their traction and some tread designs offer better traction than others; shoes follow a similar effect. The width and depth of tread grooves in shoe soles were found to significantly affect the coefficient of friction provided on wet and contaminated floors (Li et al., 2006). Boots should be maintained such that the tread depth is a minimum of 2 mm in any location (Di Pilla, 2010). In addition to housekeeping, mining companies should carefully monitor the friction provided by the walkway materials as well as that provided by the footwear when preventing slip and fall accidents.

MSHA requires that all mines utilize point-of-contact guards to protect miners from contacting hazardous moving machine parts. However, many mine companies use one large piece of grated metal that completely covers the hazard as a guard. While this meets MSHA regulations and protects the miners, it also poses a significant materials handling risk. In fact, metal covers and guards contributed to over 2,000 injuries and nearly 52,000 days lost from work. When considering the cost of hand, back, and shoulder injuries and their debilitating effects, it is essential to redesign guards such that they do not pose an additional safety hazard. Guards which are heavy may contribute to caught-in and struck by injuries when the guard slips or falls onto an employee's appendage. Reducing the weight of the guard will reduce the impact of this type of injury. It is recommended that equipment guards be modular in design, thereby decreasing the weight of each section to a manageable level, such as < 10 lb allowing for ease of assembly and disassembly. Hinges can be used to eliminate the need to handle the entire guard. Additionally, adding handles to the guards will improve coupling and eliminate exposure to pinch points thereby reducing risks for the caught in injuries associated with machine guarding. Handles should be installed such that they can be grasped by both hands and placed chest width apart. Smaller, lighter weight guards with better coupling capability will improve workers' safety when performing equipment maintenance and repair by allowing workers to handle these guards with reduced spinal loading and minimal risk of hand or finger crushing injuries (Davis et al., 1998).

Hand and finger injuries account for almost 30 percent of occupational injuries across all industries and well over one million occupational injuries in the USA annually (Oleske and Hahn, 1992; Sorock et al., 2002, 2004). Common factors in hand and finger injuries come from a multitude of areas, including worker characteristics (e.g. experience level), workplace conditions (e.g. poor tool design), transient work practices (e.g. being in a hurry), and worker capabilities (e.g. fatigue or not paying full attention to the task) (Oleske and Hahn, 1992; Sorock et al., 2004). Each factor requires its own targeted approached to reduce injury risk. It is the authors' stance that when hand injuries are viewed as independent of the environment, a company may only choose to protect their workers through protective equipment such as gloves. When protected by a glove, the hands' dexterity, flexibility, and tactile sensitivity are significantly diminished (Buhman et al., 2000). Many mining companies are starting to require employees to wear metacarpal gloves to provide impact protection for the hands and fingers. However, it is expected that metacarpal gloves will also diminish the properties of the hand, which may lead to an increase in struck by or caught in injuries. Approaching hand injuries by examining the work environment may provide a better reduction in hand injuries in the mining industry. Proper blocking of equipment, using modular guarding, adding handles to equipment and guards to reduce exposure to pinch points, and utilizing mechanical assist devices may provide more hand protection for miners than wearing a different style of glove.

Powered hand tools are generally considered to be more dangerous than non-powered hand tools (Myers and Trent, 1988). Both, however, are capable of causing traumatic and cumulative injuries as shown in this analysis as well as an analysis of other mining injuries (Lavender et al., 1986). Little research has examined over-exertion-related injury risks of both powered and non-powered hand tools. Working at or above shoulder level, flipping material, prying, and pushing are known to lead to neck and shoulder musculoskeletal disorders, back strains, and low-back pain (Holmström et al., 1992; NIOSH, 1997, 2009; Miranda et al., 2001). All of these conditions are found in mining, especially in tasks such as removing blockages from chutes and hoppers and replacing polyurethane screens which are commonly performed using pry bars or metal bars or hammers. This is likely to explain the high incidence of back and shoulder strains associated with pry bars and hammers. Improved transfer chutes may help to reduce blockage, thereby minimizing employee exposure to these hazards and manual materials handling hazards due to removing spillage.

V. Conclusions

This paper presented an analysis of maintenance and repair injuries in US surface mining facilities and plants for the years 2002-2011. To manage the risks associated with maintenance and repair in mining, plant operators must be cognizant of these risks and take steps to reduce their effects. From the injuries reported in the data set, the authors have identified the following practical recommendations to improve maintenance and repair safety in mining:

- redesign machine guarding to be modular, composed of light-weight (<10lb) pieces, and equipped with handles spaced chest width apart;
- implement improved processes such as physical barriers, improved belt maintenance and regular housekeeping to control spillage ,and maintain clear unobstructed walkways;
- regularly check walkway materials to ensure they provide adequate friction and ensure workers' boots have tread depths at least 2 mm;
- provide tool and part storage near areas where work is to be performed;
- utilize mechanical assist devices whenever possible to aid in manual materials handling;
- ensure workers wear necessary, proper-fitting hand protection when working with hand tools and around sharp parts/machines;
- add hand holds or handles on equipment to reduce worker exposure to pinch points; and
- improve transfer chutes to reduce blockage.

Some of these risks may be managed through simple interventions or in-house equipment modifications and others may require financial investments. However, there are several opportunities identified to reduce the incidence and severity of maintenance- and repair-related injuries in US surface mines and plants, which are largely preventable through the use of behavior modification, training, equipment redesign, and mechanical assist solutions.

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Dr Patrick G. Dempsey, PhD, CPE, after 11 years in various roles at the Liberty Mutual Research Institute for Safety, joined the Office of Mine Safety and Health Research of the National Institute for Occupational Safety and Health in December 2007 as the Acting Team Leader of the Musculoskeletal Disorder Prevention Team. He is a Fellow of the Ergonomics Society (UK) as well as a certified professional ergonomist. His research and practice have focussed on work-related musculoskeletal disorders, manual materials handling, ergonomics of hand-tool use, and assessing exposure to repetitive tasks. He has a BS degree in industrial engineering from the State University of New York at Buffalo, and MS and PhD degrees in industrial engineering from Texas Tech University.

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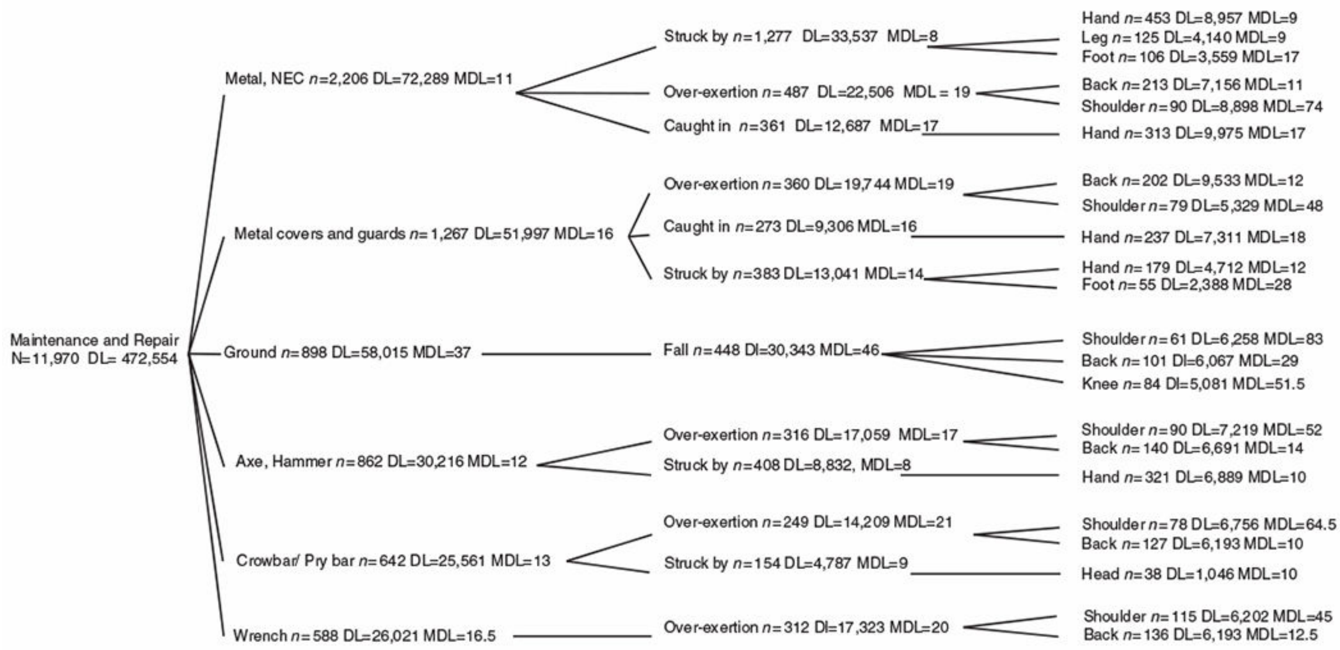

Figure 1.

Tree diagram illustrating the sources associated with the most days lost from work, the type of injury, and the body part affected

Notes: DL, total days lost; MDL, median days lost

Table I.

Percentage of accident classifications and lost workdays

Accident classification	All incidents (n = 21,799)	Unknown	Fatality	Disabilities	NDL	DL	Lost workdays (n = 473,398)	
							Total days	**Median per incident**
Handling material	7,989	75	1	131	3,229	4,553	174,551	14
Non-powered hand tools	8,669	73	3	57	4,419	4,117	141,872	12
Powered tools and machinery	2,716	22	24	87	1,177	1,406	51,817	13
Slip/trip/fall	2,425	20	9	5	497	1,894	105,158	27

Notes: DL, non-fatal injury with days lost from work; NDL, non-fatal injury with no days lost from work