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# Work-Related Unintentional Injuries

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## Introduction

Work-related injuries are a serious public health problem. In 2008 just over 5,200 workers died from injuries while at work.[1] Fatal injuries usually receive a lot of attention, but nonfatal injuries also take a heavy toll. An additional 4.4 million workers are estimated to have sustained nonfatal injuries in 2008, based on employer reports, and 3.1 million workers are estimated to have received treatment in hospital emergency departments for work-related injuries and illnesses.[1, 2] For the more serious of these injuries, the estimated direct cost in the UnitedStates is $53 billion.[3] The majority of work-related injuries are unintentional. Work-related assaults accounted for 16 percent of fatal work-related injuries and five percent of emergency department–treated injuries in 2008.[1, 2]

Injuries at work are caused by acute exposure to physical agents (e.g., mechanical energy, electricity, and chemicals). Although the immediate cause of injury is exposure to energy or deprivation of essential agents (e.g., oxygen), injury events arise from a complex interaction of factors associated with materials, the work itself, the work environment, and the worker. These factors include physical hazards in the workplace or setting; machinery- and tool-related hazards and safety features; the design of the workplace; the organization of work; the safety culture promoted by the employer, including worker training and the development and implementation of safe work practices; the availability and use of personal protective equipment; the demographic characteristics, experience, and knowledge of the worker; and economic and social factors.[4] Reducing exposures and hazards in the work environment is key to reducing work-related injuries.

## Applying the Public Health Approach to Injuries in Working Populations

Work-related injuries are not just a workforce issue, but a public health problem that impacts the health, well-being, and welfare of workers, their employers, their families, communities, and society. As a public health problem, work-related injuries can be addressed using an approach similar to that which has been applied to public health problems such as infectious disease and chronic illness—the public health model. The public health approach to prevention is based primarily on the science of epidemiology; that is, the study of the distribution and determinants of health-related states or events in specified populations and the application of this study to control health problems. Applying this approach to work-related injuries requires a multidisciplinary, organizational approach to conducting research and prevention, including collaborations among various scientific disciplines as well as partnerships with practitioners, industry, and labor in the public and private sectors.

The public health model is a stepwise, problem-solving approach consisting of the following steps:(a) identify and assign priorities to problems through data collection and monitoring (surveillance), (b) quantify and assign priorities to risk factors through analytic research, (c) identify existing or develop new strategies or technologies to prevent occupational injuries, (d) transfer and implement the most effective injury control measures, and (e) evaluate and monitor the results of intervention efforts.

The first step, collection of data, provides information on when, where, and what kind of injuries are occurring. It both guides research and provides a yardstick against which to track trends and gauge prevention efforts. The data, and the trends and patterns they reveal, are then used to map out more in-depth research. Using the analytical tools of epidemiology, risk factors and causal mechanisms that contribute to injuries can be discovered. Then strategies can be identified or developed to mitigate risk factors and prevent injuries. These strategies and interventions can then be assessed, both in the laboratory and in real workplaces, to determine their feasibility and effectiveness for prevention. Prevention measures must then be communicated and transferred to persons who can implement them in the workplace. Prevention strategies and programs that have been implemented in workplaces should be evaluated over time to ensure that they are having the intended effect.

The public health approach to work-related injury prevention requires multidisciplinary collaboration among epidemiologists, engineers, social and environmental scientists, employers, workers, and others throughout the process of developing, implementing, and evaluating options for prevention. The public health framework allows research activities to be structured sequentially, from data-driven priorities to facilitating transfer and adoption of research findings into the workplace. For some problems, the risk factors and causal mechanisms are unknown, and data collection and monitoring are necessary. For other problems, the causes are known and intervention development or evaluation of existing interventions is needed. In some areas, effective prevention measures are available but are not widely known or used, and efforts to transfer and implement them are needed. In still other instances, prevention measures do not exist or are inadequate, or options may vary in effectiveness, cost, or feasibility. The public health model provides the structure to address specific injury problems from the appropriate starting point, progressing through the prevention steps, to ultimately transfer and implement effective prevention technology and practices in the workplace.

## Work-Related Injury Data

### Data Sources

In the United States, fatal work-related injury data are considered to be complete. Since 1992, these data have been available from a system of multiple sources maintained by the Census of Fatal Occupational Injuries at the U.S. Bureau of Labor Statistics (BLS).[1] In contrast, there is not a single source of nonfatal work-related injury data in the United States. Data are available from various data sources, each of which is incomplete and overlapping. The BLS collects data from a nationally representative sample of employers.[1] Worker demographics and injury circumstances are only available from this survey for those injuries serious enough to require time away from work. In addition, this survey excludes several groups of workers, specifically federal workers, the self-employed, private household workers, and workers on farms with fewer than eleven employees. Recent research has suggested that this employer survey misses many injuries that should be counted. There are several reasons for the undercounting, including disincentives for both employers and employees to report injuries through this system.[5]

Data are also available from a nationally representative sample of hospital emergency departments, maintained by the U.S. Consumer Product Safety Commission in conjunction with the National Institute for Occupational Safety and Health (NIOSH).[6] The emergency department system includes all types of workers, but relies on (a) workers seeking emergency medical attention for their injuries, (b) workers reporting to emergency department staff that their injuries occurred at work, and (c) emergency department staff documenting the work relationship in the medical record. Research on the completeness of the national emergency department data has not been completed. Based on crude estimates, about one-third of work-related injuries are treated in emergency departments.[6] Many of the injuries reported in the BLS employer survey will also be treated in emergency departments; thus estimates from these two systems overlap and are not mutually exclusive. Although the data from the BLS employer survey and emergency department sample do not include all nonfatal work-related injuries and have limitations, they likely represent the most serious injuries, and they provide useful epidemiological data on patterns of nonfatal injury.

Though not discussed in this chapter, some data on nonfatal work-related injuries are also available from other national health surveys and systems, including the National Health Interview Survey. Detailed fatal and nonfatal work-related injury data are also available in state-specific data systems, such as medical examiner record databases and state workers' compensations systems. State-specific data are important for directing work-related injury prevention efforts at the state level, as epidemiological patterns of work-related injuries sometimes differ from national patterns. In addition, employers frequently collect injury data that can be used to direct company-specific injury prevention efforts.

## National Epidemiological Patterns

In 2008 the rate of fatal work-related injuries was 3.7 per 100,000 full-time equivalent workers, of employer-reported non-fatal injuries was 4 per 100 full-time equivalent workers,[1] and of nonfatal work-related injuries treated in hospital emergency departments was 2.2 per 100 full-time equivalent workers.[2] Work-related injuries are not randomly distributed among workplaces or workers. Injury hazards are more common in some workplaces than others. For example, fatal work injury rates are highest in agriculture, forestry, fishing, and hunting; mining; transportation and warehousing; and construction.[1] Rates in these industry sectors are 2.5 to 8 times greater than the average rate for all workers. Other industry sectors that have elevated nonfatal injury rates compared to other sectors are education and health services and manufacturing.[1] Nonfatal injury rates do not vary as much by industry sector as fatal injury rates. Industries identified here as being at high risk for injury have rates 15–20 percent higher than the average for all workers.

Work-related injuries are more common among some groups of workers. Generally, work-related injuries are more common among men than women, with men having higher injury rates than females.[1,6] This is most pronounced for fatal work-related injuries.[1] Most work-related injuries occur among those twenty-five to fifty-four years of age.[1,6] However, the highest rates of fatal injury are among the oldest workers (generally age fifty-five and older),[1] whereas the highest rates of nonfatal injuries treated in emergency departments are among workers less than twenty-five years of age.[7] Once injured, older workers have longer recuperation times (days away from work) than younger workers.[1] Hispanic and foreign-born workers have elevated fatality rates compared to other workers.[1] Most of the increased risk by worker demographic characteristics has been attributed to work in high-risk industry sectors and occupations; however, not all increased risk can be attributed to the type of work. For example, an analysis of Hispanic work-related injury deaths in the construction industry found that Hispanic workers had elevated rates when compared with non-Hispanic workers in the same occupations (e.g., laborers or roofers).[8]

The most common events leading to fatal work-related injuries are transportation incidents (the majority occurring on highways and involving motor vehicles); contact with objects and equipment (37 percent of

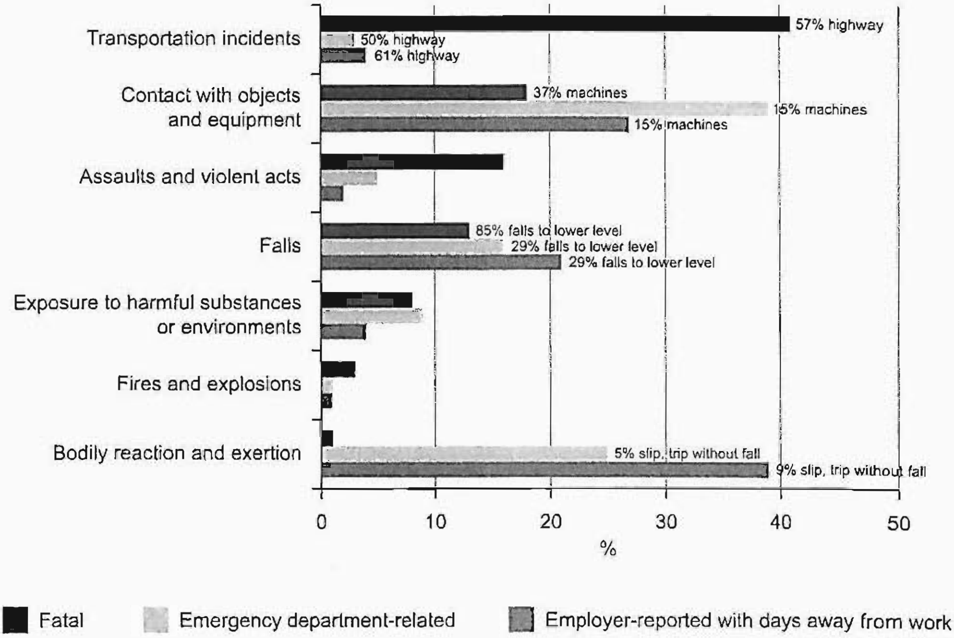


**Figure 8.1** Percent distribution of fatal, emergency department-treated, and employer-reported injuries with days away from work by event leading to injury, United States, 2008. (Fatality data [total=5,214] are from the Bureau of Labor Statistics Census of Fatal Occupational Injuries [1]. The percent of contact with objects and equipment cases associated with machines is based on primary and secondary sources of injury. Emergency department data [total=3,164,000] are preliminary estimates from the National Institute for Occupational Safety and Health, National Electronic Injury Surveillance System- Work Supplement [2]. The percent of contact with objects and equipment cases associated with machines is based on primary and secondary sources of injury. Employer-reported data [total=1,078,140] are from the Bureau of Labor Statistics Survey of Occupational Injuries and Illnesses, and are limited to private sector employees [1]. The percent of contact with objects and equipment cases associated with machines is based only on primary source of injury. Secondary sources of injury are not reported for these data.)

these incidents involve machinery); assaults and violent acts; and falls (85 percent involve falls to a lower level) (see Figure 8.1).[1] The most common events leading to nonfatal work-related injuries are contact with objects and equipment (with 15 percent of these incidents involving machinery); bodily reaction and exertion (i.e., musculoskeletal disorders, with 5 percent of these incidents involving slipping and tripping that did not result in a fall); and falls (with 29 percent involving falls to a lower level, and the majority involving falls on the same level).[1, 2] For illustrative purposes, more data are provided in subsequent sections of this chapter on common injury events associated with fatal and nonfatal, unintentional work-related injuries (i.e., motor vehicle crashes, falls, and machinery-related incidents), along with identification of risk factors and prevention strategies. Assaults are a leading cause of work-related-injury death, and there are environmental factors that contribute to them in the workplace, including worksite locations in high-crime areas, poor lighting, and poor visibility in work areas subject to robberies (e.g., convenience stores). One strategy for preventing work-related violence associated with robbery is derived from the criminal justice field and is called "crime prevention through environmental design."[9] Given this chapter's focus on *unintentional* injuries, assaults and other violence-related injuries are not discussed further.

## Tool for Identifying Prevention Strategies: The Haddon Matrix

A tool that is widely used for examining public health issues and developing prevention strategies, including work-related injuries, is the Haddon Matrix. Developed by William Haddon,[10] the matrix is based on the concept that injury causation is a chain of multifactoral events, each of which provides opportunities for intervention. The matrix provides a tool for identifying various points of intervention or application of prevention strategies by epidemiological attributes and phases in time of the injury event. It is presented as a 3 x 3 matrix, in which the columns represent the attributes of host or human factors; agent or vector factors; and physical, social, and environmental factors. The rows consist of the time phases of an injury: pre-event, event, and post-event. Multiple opportunities for injury countermeasures can be conceived within each cell. The Haddon Matrix is commonly used to brainstorm prevention strategies that could be applied to various factors at different phases in the time sequence of the event.

## Framework for Prevention in the Workplace

Employers are responsible for the safety of their workers. With few exceptions, employers have control over the work environment, including tasks and work processes, and the machinery, equipment, and tools that are used. When employers do not have control over the work environment, for example, when workers drive on roadways as part of their jobs, employers have control over when and how the work occurs. Workers also have responsibility for workplace safety. They are responsible for complying with employer policies and practices for safe work, maintaining a safe work area, using appropriate personal protective equipment when required by their employers, participating in employer-sponsored training, and reporting injuries and unsafe conditions so that they can be corrected. Ideally, employers and employees will proactively work together to identify and correct safety concerns, such as through labor-management safety committees.

In the United States, federal and state governments establish and enforce regulations to keep workers safe from recognized safety and health hazards. The Occupational Safety and Health Administration (OSHA), located in the U.S. Department of Labor, and delegated state agencies have primary responsibility for promulgating rules and guidance for worker safety. There are additional federal and state agencies with worker safety responsibilities, including the Mine Safety and Health Administration, with responsibility for safety in parts of the mining sector, and the Federal Motor Carrier Safety Administration (FMCSA), which regulates the driving of large trucks and buses. Moreover, there are numerous voluntary standards developed and promulgated by independent organizations, such as the American National Standards Institute (ANSI), that address the work environment, work practices, equipment, personal protective equipment, and worker training.

There are other groups with roles and responsibilities for worker safety. These include research organizations, such as the federal National Institute for Occupational Safety and Health (NIOSH); state public health and labor agencies, which collect and act upon occupational injury data; and numerous groups involved in advocating for worker safety and developing and disseminating worker safety guidance. The latter include labor unions, trade organizations, and nonprofit groups such as Committees on Occupational Safety and Health. It is within this framework, and with entities at different levels working together, that work-related injuries can be prevented.

## Motor Vehicle Crashes

Motor vehicle crashes (MVCs) are consistently the leading cause of work-related injury deaths in the United States. In 2008, 1,215 workers died in work-related crashes on public roadways, accounting for 23 percent of all fatalities.[1] This statistic includes only drivers and passengers in a motor vehicle, not pedestrian workers struck and killed by a motor vehicle. These crashes occurred while workers were driving as part of their jobs. Data on work-related injuries in the United States do not include motor vehicle crashes while commuting to or from work. Based on rates, crash-related deaths were highest in these sectors: transportation and warehousing; mining; and agriculture, forestry, fishing, and hunting.[11] Decedents were most often occupants of a tractor-trailer (36 percent), automobile (15 percent), or pickup truck (15 percent).[1] The estimated annual direct cost of disabling injuries due to work-related highway incidents in 2007 was $2.5 billion.[3]

The FMCSA has regulations that cover large trucks and buses,[12] but much workplace driving involves the operation of lighter-weight fleet or personal vehicles driven for work purposes, which are not regulated. The OSHA has not issued broad regulations for the driving of motor vehicles on public roadways. And although there is a voluntary consensus standard, ANSI Z15.1-2006, Safe Practices for Motor Vehicle Operations, the operation of lighter vehicles in the workplace is effectively governed by traffic laws, augmented by employer policies.[13]

### *Risk Factors*

Those who drive for work share a number of crash risk factors with other motorists, including failure to use safety belts, speeding, fatigue, distracted driving, and impaired driving. The work environment, however, may exacerbate some of these risks. A study of construction and sales workers found that compared to leisure driving, workplace driving was associated with higher levels of being in a hurry, thinking about work, tiredness, and use of mobile phones.[14] Among short-haul truck drivers, time pressure was reported to increase hazardous on-road behaviors such as exceeding speed limits.[15]

The work environment may present distracted driving risks beyond those experienced by the general motoring public. Electronic devices designed to improve productivity and efficiency may also create incentives for distracted driving (e.g., inputting or retrieving data, placing phone calls, or sending text messages while driving). A study of truck and bus drivers found that although talking or listening on a mobile phone while driving generally did not significantly increase the odds of involvement in a safety-critical event (e.g., crash, near-crash, or hard-braking in response to another vehicle), other tasks, such as text messaging, dialing, and reaching for a phone, did significantly increase the odds.[14] In contrast, others have reported that a difficult or complex phone conversation while driving poses a safety risk, even if a hands-free device is used.[17] Another study highlighted potential risks of in-vehicle information systems used in police cars.[18]

Extensive research has addressed driver fatigue and sleepiness, primarily for truck drivers.[19–21] For drivers of large trucks and buses in the United States, fatigue is a topic managed through FMCSA regulations that limit the number of consecutive duty and driving hours and mandate minimum hours of rest. Sleepiness is associated with declines in awareness, reaction times, and judgment. One study reported that 24 hours of sustained wakefulness resulted in declines in psychomotor performance equivalent to deficits associated with a blood alcohol concentration (BAC) of 0.10.[22] Research suggests that individuals' experiences of fatigue differ; therefore, uniform rules may not be the only solution to managing fatigue.[23]

### *Prevention Strategies*

Unlike other workplaces, the roadway is not a closed environment. Employers cannot control road conditions; they can, however, reduce crash risk by implementing policies and practices to promote safe driving. Increasingly, safe occupational driving has been linked to cost savings and corporate social responsibility. Interventions such as increased use of alternate, safer modes of transportation; procurement of vehicles with improved fuel economy and lower emissions; regular checks of tire pressure; and careful consideration of whether the organization's mission can be accomplished without travel by road[24] are strategies that not only improve driver safety, but also positively affect the environment.

Commitment to road safety at the highest levels of management and a comprehensive approach to safety management are seen as essential ingredients in reducing risk of work-related MVCs.[25, 26] Integration of road safety into an existing robust occupational safety and health program is a valuable enhancement.[25] In addition, employer groups and nongovernmental organizations have developed model or recommended road safety practices.[27]

Employers can set and enforce policies requiring use of safety belts and prohibit unsafe behaviors such as impaired driving and the use of mobile phones and other devices while the vehicle is in motion. Other recommended interventions include rigorous driver selection; training procedures within a comprehensive driver management program;[28] prehire checks of employee driving records and periodic checks thereafter;[13] continuing risk assessment of drivers;[28, 29] on-board driver monitoring and feedback related to speed, alertness, lane tracking, and fuel consumption;[30, 31] selection of fleet vehicles with high levels of occupant protection and advanced safety features;[25, 26] and the collection of fleet safety performance indicators.[13] Specific fatigue management strategies are important. They should focus on flexible nonregulatory alternatives[32, 33] and include route and trip planning to reduce stress and fatigue.[34]

Preventing workplace crashes rests on compliance with regulations and traffic laws, supplemented by employer-led safety initiatives. Although the volume of research is increasing,[35] there remain few studies demonstrating the quantitative safety and cost benefits of employer-based road safety programs. To support identification and diffusion of effective management principles for road safety, research is needed to develop a body of evidence and determine the most effective program components for preventing work-related MVCs.

## Falls

Falls, whether from elevations, stairs, or ladders, can occur on almost any worksite, in every industry sector.[36] Furthermore, walking and working on any surface can pose a potential hazard for falls. There were seven hundred fall-related deaths at work during 2008, 13 percent of all work-related deaths.[1] Fall-related deaths are most frequent in the construction industry; health care and social assistance, retail trade, construction, and manufacturing have the most nonfatal fall-related injuries.[1]

Falls can result in serious nonfatal injuries. An estimated 502,500 workers were treated in emergency departments for fall-related injuries in 2008, 16 percent of all worker injuries treated in emergency departments.[2] In one analysis of work-related nonfatal injuries treated in U.S. emergency departments in 2004, an estimated 22,000 workers were hospitalized for fall-related injuries, accounting for 28 percent of hospitalized cases that year.[6] Private sector employers reported an estimated 234,840 nonfatal, fall-related injuries requiring days away from work in 2008, more than one-fifth of injuries requiring days away from work in the private sector,[1] with a median of eleven days away from work per incident. This compares to a median of eight days away from work for injuries from all causes. More than 74,000 workers were estimated to have had fall-related injuries that involved more than thirty-one days away from work in 2008, 32 percent of the employer-reported fall injuries that year.[1] The estimated annual direct cost of disabling injuries due to falls at work in 2007 was $13.9 billion.[3] Additional injuries are associated with slips and trips, even when a fall does not occur.

### *Risk Factors*

Many types of work environments include fall risks, and this is the case for all occupations. Fall-related fatality rates in 2008 were highest in the construction; agriculture, forestry, fishing, and hunting; and mining industry sectors.[1, 37] Falls, both from elevations and on the same level, can occur in a variety of ways. Buildings (most notably roofs), ladders, scaffolds, stationary vehicles, steel erection structures, floor openings, and stairs and steps are common fall locations.[1]

Ladders and aerial lifts are intended to ease access for work at heights. There are many types of ladders, ranging from extension ladders and stepladders to rope ladders. Whether manufactured to be portable or fixed, ladders pose an important risk for falls. Falls from ladders occur most frequently in the construction trades, resulting in 55 percent of fatal falls and 35 percent of nonfatal falls.[1] Workers in a wide range of industries and sectors have high numbers of ladder-related deaths and injuries, including manufacturing, retail trade, information, health care and social assistance, and wholesale trade.[1]

Scaffolds are designed to be used in a variety of settings for temporary elevation. Scaffolds can be used, for example, during the construction of commercial and residential structures, for washing windows in high-rise buildings, and during maintenance. Construction workers accounted for 76 percent of falls from scaffolding in 2008.[1]

Working from elevations requires proper work procedures, injury controls, and worker training, regardless of trade. Time pressures to meet deadlines and inexperience are among the additional risks that can characterize risks for falls. Using personal protective equipment (PPE) is critical when working from elevations. Fall arrest systems, safety harnesses, and lanyards are types of personal protective equipment. Some studies show that not using the equipment available or not using it correctly poses more significant risks for workers than employers failing to make the equipment available.[36] Risk factors for slips and trips are similar to those for falls on the same level, and similar prevention strategies apply.

Falls are of particular concern for older workers, particularly those ages sixty-five and older. Data from emergency departments and the BLS employer-based survey demonstrate that older workers have elevated injury rates for nonfatal falls compared to younger workers.[1, 6] This contradicts general trends, in which older workers have lower rates of nonfatal work-related injuries.[1, 6] In 2008 falls were the leading cause of work-related injury requiring time away from work among workers ages fifty-five and older, accounting for 33 percent of injuries reported by employers for workers of this age group. Falls to the same level accounted for about three-quarters of the fall-related injuries among workers ages fifty-five and older.[1] With the aging of the U.S. workforce, it is imperative that work-related fall prevention efforts both improve and increase.

### *Prevention Strategies*

Some working populations face nearly constant exposure to fall hazards, especially construction and utility workers. Good housekeeping at a work-site is a good practice for fall prevention, whether from an elevation or on the same level. A proper shoe for the task and the worksite is another important fall prevention strategy. Fall-protection programs, written to meet at least the minimal OSHA requirements,[38] can reduce the number of fall-related injuries at work. Such programs should be prepared, implemented, and enforced by employers in every industry. Effective fall prevention systems have both passive and active components, and employers bear the responsibility of providing protection to their workers. Examples of passive components include guardrails, safety nets, and hole covers. Active systems are designed to back up passive systems or to be in place where passive components are not feasible. Active systems can include tie-offs with self-retracting lifelines to supporting structures, lanyards, and body harnesses as part of a fall arrest system.

Employers should train their employees and contractors to recognize and identify fall hazards and implement fall prevention systems. Hands-on demonstrations should complement classroom instruction, especially for safety equipment, and refresher training opportunities (e.g., "toolbox talks") are critical as well. Employers and employees should plan work well and incorporate safety, especially when the work setting or tasks will change frequently, or when the work environment has many activities going on simultaneously (e.g., construction sites). Furthermore, employers should conduct both scheduled and unscheduled safety inspections.

## Machinery-Related Injuries

Machinery is defined by BLS as a combination of smaller machines (elements or parts) that is capable of motion and is contained in a stationary frame.[39] Handheld power tools are classified separately as "Handtools—powered."[1] It is clear from the BLS data that machinery-related injuries take a heavy toll on American workers and employers. Based on the BLS data, in 2008 there were 604 fatal injuries with machinery as the primary or secondary source of the injury.[1] Construction, logging, and mining machinery were the primary or secondary injury source for 166 of the fatalities. Specifically, excavating machinery (such as bulldozers and backhoes) and loaders (including bucket loaders and front-end loaders) were responsible for 61 and 58 fatal injuries, respectively. Material-handling machinery was responsible for 251 fatal injuries. Within this category, cranes and elevators had 93 and 91 fatal injuries, respectively, with powered conveyors the source of 24 fatalities.

In 2008 machinery was the source of nonfatal injury for 64,170 cases involving days away from work reported by employers.[1] Metal, woodworking, and special material machinery (e.g., saws, lathes, presses) was responsible for 13,570 cases. Within this group, stationary sawing machinery had the most injuries of any single machine type (n = 4,520). Special process machinery (e.g., food processing and medical equipment) was the source for 11,700 cases. Food slicers alone caused 3,390 lost work day cases. Data from 2008 show 3,260 amputation injuries requiring days away from work with machinery as a primary injury source. The two types of machinery with the most amputations were table saws (n = 190) and food slicers (n = 190). More than 25 percent of all machinery-related injuries that involved days away from work resulted in more than thirty-one days away from work. In addition, the OSHA has estimated the average total costs (indirect plus direct costs) for an amputation injury to be $101,467.[40]

*Risk Factors*

Contact with objects and equipment was the event or exposure responsible for 937 fatal injuries in the 2008 data.[1] Of these fatalities, 520 were due to being struck by an object or equipment, and 302 were caught in or compressed by equipment or objects. In general, the following types of machine motions lead to most injuries among operators and bystanders: rotation; reciprocating or transverse motion; in-running nip points or pinch points; cutting actions; and punching, shearing, and bending. Safeguards for these motions generally can be categorized in two groups: mechanical power transmission safeguards and point-of-operation safeguards.

Machinery such as aerial lifts, cranes, loaders, and excavating machinery provides unique challenges for worker safety because of the mobility of the equipment within and around the work area, with workers on foot. Other issues to consider are the impact that environmental factors, such as inclement weather and visibility (e.g., nighttime work), can have on worker safety. McCann[41] evaluated causes of death in the excavation industry for 1992–2002 and found, based on coding categories, that the single largest cause of death was moving vehicle incidents (46 percent of total deaths). This classification includes events in which workers were struck by a moving vehicle.

Fatal injuries can also be the result of missing, inadequate, or circumvented safeguarding. Furthermore, many incidents that lead to fatal injuries with machinery are the result of inadequate or nonexistent lockout/tagout safety programs. Data from an investigation of machinery-related fatalities identified 592 lockout-/tagout-related cases that resulted in 624 deaths. In over 58 percent of the cases, lockout procedures were not attempted.[42] Lockout/tagout is described in and regulated by the OSHA and requires that sources of hazardous energy be deenergized and either locked in a nonhazardous configuration (lockout) or tagged with appropriate signage indicating this condition (tagout).[43, 44] Hazardous energy sources to be considered include chemical, electrical, hydraulic, mechanical, pneumatic, thermal, and stored energy. Lockout/tagout procedures are particularly important during maintenance or nonroutine operation (e.g., machine or equipment jam). In 2009 lockout and tagout was listed by the OSHA as the fifth most cited violation.[45]

Many of the risk factors applicable to fatal machine-related injury also apply to nonfatal machine-related injury. Numerous studies have noted lack of adequate machine safeguarding as a primary contributing factor. For example, in a study of forty small metal fabrication businesses, Parker et al.[46] found that more than 40 percent of safeguarding devices were either missing or inadequate in all machines evaluated. Unusual or non-routine work can also be a risk factor. Research has shown that the relative risk of hand injury was increased when working with equipment, tools, or work pieces not performing as expected, or when using a different work method.[47] This same study also demonstrated a slightly smaller influence on injury when performing an unusual task.

### *Prevention Strategies*

For material-moving machinery, prevention efforts are especially challenging because of the mobile nature of these types of machinery. Some basic prevention strategies include maintaining a safe clearance from mobile equipment and training all workers on this policy, with particular emphasis on equipment blind areas (i.e., areas behind and around equipment where operators are unable to adequately see workers because of the size and design of the equipment). Special consideration must also be applied to work situations with additional environmental conditions, such as operating equipment at night or in inclement weather with limited visibility. Additional concerns include mobile machinery that might not be heard in noisy environments, even though it is equipped with backup alarms or other warning devices. In these situations, it is particularly important that employers establish traffic control plans to separate employees and bystanders from moving equipment. The use of ground spotters to help operators safely navigate equipment in work areas is another useful strategy.

For stationary machinery, review of research in the area of occupational injuries suggests that many of these injuries could be prevented through adequate safeguarding or implementation of lockout/tagout procedures. For example, OSHA requires employers to establish a program for control of hazardous energy.[43] Information on consensus standards for control of hazardous energy can be found in ANSI Z244.1.[48] Safeguarding, risk reduction standards, and guidelines are available from the OSHA, the ANSI, and the International Organization for Standardization (ISO).

Safeguarding devices, awareness devices, and safeguarding methods may all be used to protect workers from machine injuries. Examples of safeguarding devices include fixed barrier guards, which prevent the worker's contact at the point of operation where machining processes take place or contact with hazardous machine parts, such as power transmission components, which provide machine motions (e.g., gears, shafts, and belts). Other machine safeguards include electro-optical, radio frequency, and area scanning presence-sensing devices. Typically, these types of devices are integrated into machine control mechanisms so as to interrupt hazardous machine motions should any part of a worker's body "break" the zone of protection covered by these safeguards. Awareness devices are usually barriers, signals, or signs that separate workers from hazardous machine components or provide a warning to avoid these areas. Other safeguarding methods include concepts such as safe distance and safe location safeguarding, for which the objective is to keep the worker a safe distance away from the hazard. An example of safe distance safeguarding includes machine operation design so that both hands are required to be a safe distance from hazards for proper machine operation (e.g., through the use of two-hand control devices for machine activation).

Another effective prevention strategy for stationary machinery is to plan for control of hazardous energy during routine and nonroutine machine, and/or equipment operation and maintenance. In addition to following OSHA regulations,[43] the NIOSH recommends that before beginning machine maintenance, employers develop and implement a hazardous energy control program that includes use of both lockout and tagout procedures. An effective hazardous energy control program would include (a) identifying and labeling all hazardous energy sources; (b) deenergizing, locking out, and tagging all sources of hazardous energy; (c) blocking or dissipating any stored energy; (d) verifying by test or observation that all energy sources are deenergized before beginning work; (e) inspecting repair work before removing lockout/tagout devices; and (f) ensuring that all workers are clear of danger points before reenergizing machinery.[49] Hazardous energy control programs should be written, periodically reviewed, and updated, and workers should be trained on all procedures, including periodic refresher training.

Industrial machines are vital assets to a healthy economy and workforce. It is essential, however, that injury hazards and risks associated with working with machinery be identified and appropriate controls be implemented, to provide a safer work environment for workers who operate and maintain machinery.

## Conclusion

Injuries and deaths at work are a significant public health problem. Work-related unintentional injuries take a large toll on the workforce, and the impact extends beyond the workplace to encompass workers' families, communities, and society. Injuries at work are not random events, but rather occur through a chain of events, thus making them both predictable and preventable. Prevention strategies proceed from a better understanding of exposures, risks, and target populations in work settings. Preventing these injuries requires the consistent and concerted efforts of multiple parties using multiple strategies. Combinations of employers, workers, public health and safety practitioners, researchers, regulators, and policy makers have a share in the responsibility for prevention, and all should devote their best efforts to reducing the burden of injuries at work.

## Notes

1. Bureau of Labor Statistics, United States Department of Labor, Workplace injuries, 2010, www.bls.gov/data/home.htm#injuries (accessed September 27, 2010).
2. National Institute for Occupational Safety and Health, unpublished data from the *National electronic injury surveillance—Occupational supplement (NEISS-Work)* (Morgantown, WV: Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Safety Research, 2010).
3. Liberty Mutual Research Institute for Safety, *The most disabling workplace injuries cost industry an estimated $53 billion* (Boston: Liberty Mutual, 2009).
4. D. N. Castillo, T. J. Pizatella, and N. A. Stout, Injuries and occupational safety, in *Occupational and environmental health*, 6th ed., edited by B. Levy, D. Wegman, S. L. Baron, and R. K. Sokas (New York: Oxford University Press, 2011).
5. Committee on Education and Labor, U.S. House of Representatives, *Hidden tragedy: Underreporting of injuries and illnesses: A majority staff report by the Committee on Education and Labor, U.S. House of Representatives*, Report number 42-881 PDF (Washington, DC: U.S. Government Printing Office, 2008).

6. S. Derk, S. M. Marsh, and L. L. Jackson, Nonfatal occupational injuries and illnesses—United States, 2004, *Morbidity and Mortality Weekly Report* 56 (16) (2007): 393–397.
7. C. R. Estes, L. L. Jackson, and D. N. Castillo, Occupational injuries and deaths among younger workers—United States, 1998–2007, *Morbidity and Mortality Weekly Report* 59 (2010): 449–455.
8. X. Dong and J. Platner, Occupational fatalities of Hispanic construction workers from 1992 to 2000, *American Journal of Industrial Medicine* 45 (2004): 45–54.
9. N. A. Stout, D. N. Castillo, H. E. Amandus, and Y. J. Pizatella, Occupational injuries and work place violence, in *International encyclopedia of public health,* 3rd ed., edited by K. Heggenhougen and S. R. Quah (Amsterdam and Boston: Elsevier Inc., 2008).
10. W. Haddon Jr., The changing approach to the epidemiology, prevention, and amelioration of trauma: The transition to approaches etiologically rather than descriptively based, *American Journal of Public Health* 58 (1968): 1431–1438.
11. The fatality rates were calculated per 100,000 full-time equivalent workers by S. Pratt using numerator and denominator data available on the U.S. BLS Web site and employing the same methods used by the BLS.
12. See www.fmcsa.dot.gov for access to the Federal Motor Carrier Safety Regulations and for information about DOT medical programs and commercial driver licensing.
13. American National Standards Institute, *Safe practices for motor vehicle operations*, ANSI/ASSE Z15.1–2006 (New York: American National Standards Institute, 2006).
14. S. Salminen and E. Lähdeniemi, Risk factors in work-related traffic, *Transportation Research. Part F: Traffic Psychology and Behaviour* 5 (2002): 375–384.
15. R. Friswell and A. Williamson, Work characteristics associated with injury among light/short-haul transport drivers, *Accident Analysis & Prevention* 42 (6) (2010): 2068–2074.
16. J. S. Hickman, R. J. Hanowski, and J. Bocanegra, *Distraction in commercial trucks and buses: Assessing prevalence and risk in conjunction with crashes and near-crashes*, Report no. FMCSA-RRR-10–049 (Blacksburg: Virginia Tech Transportation Research Institute, 2010).

17. C. J. D. Patten, A. Kircher, J. Östlund, and L. Nilsson, Using mobile telephones: Cognitive workload and attention resource allocation, *Accident Analysis & Prevention* 36 (3) (2003): 341–350.
18. P. Hampton and M. Langham, A contextual study of police car telematics: The future of in-car information systems, *Ergonomics* 48 (2) (2005): 109–118.
19. I. D. Brown, Driver fatigue, *Human Factors* 36 (2) (1994): 298–314.
20. M. M. Mitler, J. C. Miller, J. J. Lipsitz, et al., The sleep of long-haul truck drivers, *New England Journal of Medicine* 337 (11) (1997): 755–761.
21. R. J. Hanowski, J. Hickman, M. C. Fumero, et al., The sleep of commercial vehicle drivers under the 2003 hours-of-service regulations, *Accident Analysis & Prevention* 39 (6) (2007): 1140–1145.
22. D. Dawson and K. Reid, Fatigue, alcohol, and performance impairment, *Nature* 388 (1997): 235.
23. P. A. Desmond and G. Matthews, Individual differences in stress and fatigue in two field studies of driving, *Transportation Research. Part F: Traffic Psychology and Behaviour* 12 (4) (2009): 265–276.
24. United Nations Environment Program, *UNEP green driving*, Nairobi, Kenya, 2010, http://www.greener-driving.net/site/more.html (accessed October 26, 2010).
25. N. Haworth, C. Tingvall, and N. Kowadlo, *Review of best practice road safety initiatives in the corporate and/or business environment*, MUARC report no. 166 (Clayton, Victoria, Australia: Monash University Accident Research Centre, 2000).
26. S. Pratt, *Work-related roadway crashes: Challenges and opportunities for prevention* (Cincinnati, OH: Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, 2003).
27. See, for example, the Network of Employers for Traffic Safety in the U.S., http://www.trafficsafety.org; "Driving for Better Business" in the United Kingdom, http://www.drivingforbetterbusiness.com; and the PRAISE project of the European Transport Safety Council, http://www.etsc.eu/PRAISE.php.
28. J. Davey, D. Wishart, J. Freeman, and B. Watson, An application of the driver behaviour questionnaire in an Australian organisational

fleet setting, *Transportation Research. Part F: Traffic Psychology and Behaviour* 10 (1) (2007): 11–21.
29. P. Darby, W. Murray, and R. Raeside, Applying online fleet driver assessment to help identify, target and reduce occupational road safety risks, *Safety Science* 47 (3) (2009): 436–442.
30. I. J. Wouters and J. M. Bos, Traffic accident reduction by monitoring driver behaviour with in-car data recorders, *Accident Analysis & Prevention* 32 (2000): 643–650.
31. L. Barr, S. Popkin, and H. Howarth, *An evaluation of emerging driver fatigue detection measures and technologies*, FMCSA-RRR-09-005 (Cambridge, MA: Volpe National Transportation Systems Center, 2009).
32. A. M. Feyer and A. M. Williamson, Broadening our view of effective solutions to commercial driver fatigue, in *Stress, workload, and fatigue*, edited by P. A. Hancock and P. A. Desmond (Mahwah, NJ: Lawrence Erlbaum Associates, 2001), 550–565.
33. P. Gershon, D. Shinar, and A. Ronen, Evaluation of experience-based fatigue countermeasures, *Accident Analysis & Prevention* 41 (5) (2009): 969–975.
34. Department for Transport, *Safety culture and work-related road accidents*, Road safety research report no. 51 (London: Department for Transport and BOMEL Limited, 2004).
35. N. P. Gregersen, B. Brehmer, and B. Morén, Road safety improvement in large companies: An experimental comparison of different measures, *Accident Analysis & Prevention* 28 (3) (1996): 297–306.
36. C. M. Branche, An assessment of conditional risks for severe occupational traumatic injury among North Carolina construction workers (dissertation, University of North Carolina, Chapel Hill, 1988).
37. The fatality rates were calculated by D. Castillo using numerator and denominator data available on the U.S. BLS Web site and employing the same methods used by the BLS.
38. R. W. Braddee, M. G. Hause, and S. G. Pratt, *Worker deaths by falls: A summary of surveillance findings and investigative case reports*, DHHS (NIOSH) publication no. 2000–116 (Cincinnati, OH: Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, 2000).

39. Machines that are primarily used for transporting people or materials are classified as "vehicles."
40. Occupational Safety and Health Administration, United States Department of Labor, Small business assistance, www.osha.gov/dcsp/smallbusiness/safetypays/estimator.html (accessed October 8, 2010).
41. M. McCann, Heavy equipment and truck-related deaths on excavation work sites, *Journal of Safety Research* 37 (2006): 511–517.
42. M. T. Bulzacchelli, J. S. Vernick, et al., Circumstances of fatal lockout/tagout-related injuries in manufacturing, *American Journal of Industrial Medicine* 51 (2008): 728–734.
43. Occupational Safety and Health Administration, United States Department of Labor, Regulations (standards 29 C.F.R.), http://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=1&p_keyvalue=1910 (accessed December 11, 2010).
44. Tagout without lockout is permitted by the OSHA when tagout can be demonstrated to provide equivalent protection.
45. L. Walter, National Safety Council (NSC): OSHA's top 10 most cited violations, *EHS Today* (2009), http://ehstoday.com/standards/osha/nsc-osha-top-most-cited-violations-1029/ (accessed October 8, 2010).
46. D. L. Parker, L. M. Brosseau, et al., A randomized, controlled intervention of machine guarding and related safety programs in small metal-fabrication businesses, *Public Health Reports* 124 (supp. 1) (2009): 90–100.
47. G. S. Sorock, D. A. Lombardi, et al., Acute traumatic occupational hand injuries: Type, location, and severity, *Journal of Occupational and Environmental Medicine* 44 (4) (2002): 345–351.
48. American National Standards Institute, *Safety requirements for the lockout/tagout of energy sources*, ANSI/ASSE Z244.1–2003 (R2008) (New York: American National Standards Institute, 2008).
49. National Institute for Occupational Safety and Health, *Preventing worker deaths from uncontrolled release of electrical, mechanical, and other types of hazardous energy*, DHHS (NIOSH) publication no. 99-110 (Morgantown, WV: Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Safety Research, 1999).