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Struck-by and Caught-in Hazards:

An Interdisciplinary Annotated Bibliography

CPWR - The Center for Construction Research and Training

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8484 Georgia Avenue
Suite 1000
Silver Spring, MD 20910

PHONE: 301.578.8500
FAX: 301.578.8572

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Struck-By and Caught-In Hazards: An Interdisciplinary Annotated Bibliography

Albers, J. T., et al. (2014). "Residential building stakeholders' attitudes and beliefs regarding nail gun injury risks and prevention." New Solut 23(4): 577-605.

Pneumatic nail guns are ubiquitous at residential construction sites across the United States. These tools are noted for the traumatic injuries that can occur from their operation. Different trigger mechanisms on these tools are associated with different levels of risk. Residential building subcontractors and workers, both native-born and immigrant, were brought together in focus groups to discuss their attitudes and beliefs regarding risk factors for nail gun injury as well as barriers to the adoption of safer technology. Participants' comments are organized first by influences on traumatic injury occurrence or prevention and later by sociotechnical system category. Participants attributed influences on injury risk to personal and external causation factors in all sociotechnical system categories; however, participants more frequently described influences on injury prevention as related to workers' behaviors, rather than to external factors. A discussion of these influences with respect to attribution theory and sociotechnical models of injury causation is presented.

Albert, A., et al. (2020). "Focus on the fatal-four: Implications for construction hazard recognition." Safety science 128: 104774.

Much effort has been devoted to improving hazard recognition in the construction industry. One such effort is the training outreach program pioneered and promoted by the Occupational Safety and Health Administration (OSHA) – commonly known as the Construction Focus Four or the Construction Fatal Four program. This program which is integrated in much of the training efforts offered in the construction industry seeks to promote hazard recognition and management by focusing on the four leading causes of fatal incidents – namely falls, caught-in/between, struck-by, and electrocution (i.e., fatal-four) hazards. Given the emphasis of these hazards in most training efforts, the objective of the current research was to explore if there are any performance disparities among workers in recognizing hazards that fall under the fatal-four and the non-fatal-four hazard categories. To accomplish this research goal, more than 280 workers were recruited from 57 construction workplaces in the United States to participate in a hazard recognition activity. The results of the study reveal that workers fail to recognize a disproportionate number of safety hazards in both the fatal-four and the non-fatal-four hazard categories. However, workers are relatively more proficient in recognizing hazards in the fatal-four hazard category than the non-fatal-four hazard category. More specifically, on average, the participating workers roughly recognized 57% of the fatal-four safety hazards while only recognizing 18% of the non-fatal-four safety hazards. Collectively, these findings suggest that apart from focusing on the fatal-four hazards, training efforts must also focus on the non-fatal-four safety hazards – given the relative poor performance.

Arboleda, C. A. and D. M. Abraham (2004). "Fatalities in trenching operations—analysis using models of accident causation." Journal of Construction Engineering and Management 130(2): 273-280.

More than 65 construction workers are killed each year due to trench related accidents. Accident prevention begins with having a clear understanding of the causes of these accidents. This paper discusses the analysis of 296 fatality reports related to trenching operations from the Occupational Safety and Health Administration (OSHA) in the 1997-2001 time frame. In this paper, two models will be considered to analyze the fatality reports and to find the major relationships between the 'how' and the 'why' of trenching fatalities. The first model considers the causes related to

physical processes, and the second model evaluates causes that can be linked to human behavior. The understanding of the major links between these two models and other factors will help to develop more effective strategies to prevent trenching fatalities

Arditi, D., et al. (2007). "Fatal accidents in nighttime vs. daytime highway construction work zones." J Safety Res 38(4): 399-405.

INTRODUCTION: Awareness about worker safety in nighttime construction has been a major concern because it is believed that nighttime construction creates hazardous work conditions. However, only a few studies provide valuable comparative information about accident characteristics of nighttime and daytime highway construction activities. METHOD: This study investigates fatal accidents that occurred in Illinois highway work zones in the period 1996-2001 in order to determine the safety differences between nighttime and daytime highway construction. The lighting and weather conditions were included into the study as control parameters to see their effects on the frequency of fatal accidents occurring in work zones. RESULTS: According to this study, there is evidence that nighttime construction is more hazardous than daytime construction. The inclusion of a weather parameter into the analysis has limited effect on this finding. IMPACT ON INDUSTRY: The study justifies establishing an efficient work zone accident reporting system and taking all necessary measures to enhance safety in nighttime work zones.

Beavers, J., et al. (2009). "Steel erection fatalities in the construction industry." Journal of Construction Engineering and Management 135(3): 227-234.

Construction fatalities continue to occur during steel erection. Using 166 case files resulting from Occupational Safety and Heath Administration (OSHA) investigations of steel erection fatalities during the years 2000–2005, the writers examined the data to determine the proximal causes and contributing physical factors. Of the 166 fatal events, results showed proximal cause “falls” represented 125 of the fatal events, “crushed/struck/hit by object” represented 40, and one was caused by electrocution. The rate of fatalities tended to reduce from 2000 to 2005. As a result, OSHA may be reaching one of its goals established following the introduction of the new steel standards in 2002, an annual reduction of 30 fatalities. The results of this study indicate that employer compliance with OSHA’s fall protection standards and instructing employees in recognition and avoidance of unsafe conditions could save lives.

Chan, K., et al. (2020). "Incorporating Worker Awareness in the Generation of Hazard Proximity Warnings." Sensors (Basel) 20(3).

Proximity warning systems for construction sites do not consider whether workers are already aware of the hazard prior to issuing warnings. This can generate redundant and distracting alarms that interfere with worker ability to adopt timely and appropriate avoidance measures; and cause alarm fatigue, which instigates workers to habitually disable the system or ignore the alarms; thereby increasing the risk of injury. Thus, this paper integrates the field-of-view of workers as a proxy for hazard awareness to develop an improved hazard proximity warning system for construction sites. The research first developed a rule-based model for the warning generation, which was followed by a virtual experiment to evaluate the integration of worker field-of-view in alarm generation. Based on these findings, an improved hazard proximity warning system incorporating worker field-of-view was developed for field applications that utilizes wearable inertial measurement units and localization sensors. The system's effectiveness is illustrated through several case studies. This research provides a fresh perspective to the growing adoption of wearable sensors by incorporating

the awareness of workers into the generation of hazard alarms. The proposed system is anticipated to reduce unnecessary and distracting alarms which can potentially lead to superior safety performance in construction.

Chen, G. X., et al. (2000). "Expanded analysis of injury mortality among unionized construction workers." Am J Ind Med 37(4): 364-373.

BACKGROUND: To evaluate the utility of expanding the number and precision of injury categories used in previous occupational mortality studies, this study reanalyzed data from four previous studies of unionized construction workers (construction laborers, ironworkers, sheet metal workers, and operating engineers), by expanding the number of injury categories from 6 to 33. METHODS: Proportionate mortality ratios (PMRs) were computed using the distribution of deaths from the National Occupational Mortality Surveillance System, a mortality surveillance system from 28 states, as a comparison. A blue collar comparison group was also used in additional analyses to adjust for socioeconomic and other factors. RESULTS: This reanalysis identified significantly elevated PMRs in at least one of the four worker groups for falls, motor vehicle crashes, machinery incidents, electrocutions, being struck by falling objects, being struck by flying objects, explosions, suffocation, and water transport incidents. Limiting the comparison population to deaths among blue collar workers did not change the results substantially. CONCLUSIONS: This study demonstrates that increasing the precision of categories of death from injury routinely used in mortality studies will provide improved information to guide prevention. Am. J. Ind. Med. 37:364-373, 2000. Published 2000 Wiley-Liss, Inc.

Cheng, T. and J. Teizer (2014). "Modeling tower crane operator visibility to minimize the risk of limited situational awareness." Journal of Computing in Civil Engineering 28(3).

Many construction fatalities involving cranes and ground workers are caused by contact with objects and equipment, in particular being struck by crane loads and parts. One of the main risks in operating a tower crane is the limited visibility of the crane operator. An approach is presented that aims at increasing the situational awareness of a tower crane operator by aligning enhanced understanding of construction site layout with increased operator visibility of ground level operations. The developed method uses sensors to collect two data types, as follows: (1) a laser scanner measures the as-built conditions and geometry of a construction site, and (2) real-time location-tracking technology gathers the mostly dynamic location of workers on the ground. Several algorithms are presented to (1) identify blind spaces from the collected point cloud data that limit the visibility of a crane operator, (2) process real-time location-tracking data of workers on the ground, and (3) fuse the resulting data to create information that allows a quantitative assessment of the situational awareness of a tower crane operator. Results to a field trial are presented and show that a tower crane operator using the developed approach can increase understanding of where and when occluded spaces and ground-level operations occur. The developed methods for creating safety information from range point cloud and trajectory data is a promising approach in significantly improving the currently unsafe operation of tower cranes, one of the most utilized pieces of equipment in construction. © 2014 American Society of Civil Engineers.

Cho, Y. K., et al. (2017). "Improving Work Zone Safety Utilizing a New Mobile Proximity Sensing Technology (CPWR Report) ".

Choi, S. D. and K. Carlson (2014). "Occupational safety issues in residential construction surveyed in wisconsin, United States." Ind Health 52(6): 541-547.

Residential construction is a high-risk industry in the U.S. due to the exposure to workrelated safety hazards and fall injuries. This study aimed to examine the safety training and safe work practices of construction workers within the small residential construction industry. In order to achieve the study objectives, a survey was designed and sent to approximately 200 Wisconsin based residential construction contractors. About one third of the respondents stated that they did not have any form of safety programs. The study indicated that the most common types of workrelated injuries in residential construction were slips/trips/falls and cuts/lacerations. The survey findings also suggested that the residential construction contractors needed to increase the utilization of fall protection safety equipment. Further education and subject matter expert training could provide benefits to improve occupational safety and health of the small business workforce in the residential construction industry. © 2014 by National Institute of Occupational Safety and Health.

Courtney, T. K., et al. (2002). "Disabling occupational injury in the US construction industry, 1996." J Occup Environ Med 44(12): 1161-1168.

In 1996 the US construction industry comprised 5.4% of the annual US employment but accounted for 7.8% of nonfatal occupational injuries and illness and 9.7% of cases involving at least a day away from work. Information in the published literature on the disability arising from construction injuries is limited. The construction claims experience (n = 35,790) of a large workers' compensation insurer with national coverage was examined. The leading types and sources of disabling occupational morbidity in 1996 in the US construction industry were identified. Disability duration was calculated from indemnity payments data using previously published methods. The average disability duration for an injured construction worker was 46 days with a median of 0 days. The most frequently occurring conditions were low back pain (14.8%), foreign body eye injuries (8.5%), and finger lacerations (4.8%). Back pain also accounted for the greatest percentage of construction claim costs (21.3%) and disability days (25.5%). However, the conditions with the longest disability durations were sudden-onset injuries, including fractures of the ankle (median = 55 days), foot (42 days), and wrist (38 days). Same-level and elevated falls were the principal exposures for fractures of the wrist and ankle, whereas elevated falls and struck by incidents accounted for the majority of foot fractures. Manual materials handling activities were most often associated with low back pain disability. The results suggest that these most disabling injuries can be addressed by increasing primary prevention resources in slips and falls and exposures related to injuries of sudden-onset as well as in reducing manual materials handling and other exposures associated with more gradual-onset injuries.

Deatherage, J. H., et al. (2004). "Neglecting safety precautions may lead to trenching fatalities." Am J Ind Med 45(6): 522-527.

BACKGROUND: Trench collapses ranked as the seventh leading cause of the possible twenty-nine causes of OSHA-inspected fatal construction events during the period 1991-2001. This study aims to examine why these fatalities occurred. METHODS: Forty-four case files from OSHA inspections of fatal trench collapses were reviewed. RESULTS: Improper protection of the excavation site where work was taking place was the leading fatality cause. Several organizational or physical conditions were present at many fatal sites; the most frequent was that no training had been provided for trenching. CONCLUSIONS: Presence of a competent, diligent person at the site would

have prohibited most fatalities. The top cited violation was lack of protection, that is, benching, shoring, sloping, trench boxes, etc. (29 CFR 1926.652 (a) (1)).

Dement, J. M., et al. (2003). "Nail gun injuries among construction workers." Appl Occup Environ Hyg 18(5): 374-383.

Pneumatic nail guns greatly increase worker productivity and are extensively used in wood frame building construction, with especially high use in residential construction. One surveillance report of nail gun injuries in Washington State has been published; however, other literature consists largely of case reports and case series in trauma journals. The major objective of the current study was to investigate the occurrence of nail gun-associated injuries among construction workers and to identify preventable work-related factors associated with these injuries. Nail gun-related injuries occurring among a cohort of 13,347 carpenters in Ohio who worked union hours during the time period January 1, 1994, until September 30, 1997, were identified by matching the cohort with workers' compensation claims made to the Ohio Bureau of Workers' Compensation. We also analyzed workers' compensation claims for North Carolina Home Builders Association members for the period July 1996-November 1999 to identify nail gun-related injuries. Analyses included stratified analyses of claims by nature and body part injured, calculation of nail gun injury rates, and analyses of free text descriptions of injuries. Overall, nail gun injuries were responsible for 3.9 percent of workers' compensation claims with 8.3 percent to 25.5 percent of claims involving paid lost work time. The overall rate of nail gun injuries (cases per 200,000 work hours) was 0.33 in North Carolina and 0.26 in Ohio, reflecting the greater concentration of wood frame construction workers in the North Carolina population studied. Higher rates of injury were observed for carpenters in North Carolina and among residential carpenters in Ohio. The predominant body part injured was the hands/fingers, with 80 to 89 percent of injuries being nail punctures. Analyses of free text information for puncture injuries found approximately 70 percent of injuries to occur during the framing/sheathing stage of construction. Our data suggest that approximately 69 percent of puncture injuries may be due to an inadvertent gun discharge or misfire, preventable in large part by the use of sequential triggers. Worker training and education also are important components of nail gun injury prevention.

Dong, X., et al. (2014). "Fatalities in the construction industry: findings from a revision of the BLS Occupational Injury and Illness Classification System." Monthly Lab. Rev. 137: 1.

Dong, X. S., et al. (2014). "Risks of a lifetime in construction Part I: Traumatic injuries." Am J Ind Med 57(9): 973-983.

Background: Estimates of occupational risk are typically computed on an annual basis. In contrast, this article provides estimates of lifetime risks for fatal and nonfatal injuries among construction workers. A companion paper presents lifetime risks for occupational illnesses. Methods: Using 2003-2007 data from three large data sources, lifetime risk was computed based on the number of fatal and nonfatal injuries per 100 FTEs for a working lifespan of 45 years. Results: For a working life in construction, the risk of fatal injuries were approximately one death per 200 FTE, and the leading causes were falls and transportation incidents. For nonfatal injuries resulting in days away from work, the adjusted lifetime risk was approximately 78 per 100 FTEs, and the leading causes were contact with objects/equipment, overexertion, and falls to a lower level. Conclusions: Lifetime risk estimates help inform both workers and policymakers. Despite improvements over the

past decades, risks in construction remain high. Am. J. Ind. Med. 57:973-983, 2014. © 2014 Wiley Periodicals, Inc.

Eiris, R., et al. (2018). "PARS: Using Augmented 360-Degree Panoramas of Reality for Construction Safety Training." Int J Environ Res Public Health 15(11).

Improving the hazard-identification skills of construction workers is a vital step towards preventing accidents in the increasingly complex working conditions of construction jobsites. Training the construction workforce to recognize hazards therefore plays a central role in preparing workers to actively understand safety-related risks and make assertive safety decisions. Considering the inadequacies of traditional safety-training methods (e.g., passive lectures, videos, demonstrations), researchers have employed advanced visualization techniques such as virtual reality technologies to enable users to actively improve their hazard-identification skills in a safe and controlled environment. However, current virtual reality techniques sacrifice realism and demand high computational costs to reproduce real environments. Augmented 360-degree panoramas of reality offers an innovative alternative that creates low-cost, simple-to-capture, true-to-reality representations of the actual construction jobsite within which trainees may practice identifying hazards. This proof-of-concept study developed and evaluated a platform using augmented 360-degree panoramas of reality (PARS) for safety-training applications to enhance trainees' hazard-identification skills for four types of sample hazards. Thirty subjects participated in a usability test that evaluated the PARS training platform and its augmented 360-degree images captured from real construction jobsites. The usability reviews demonstrate that the trainees found the platform and augmentations advantageously to learning hazard identification. The results of this study will foreseeably help researchers in developing engaging training platforms to improve the hazard-identification skills of workers.

Elelu, K., et al. (2022). "Augmented Hearing of Auditory Safety Cues for Construction Workers: A Systematic Literature Review." Sensors (Basel) 22(23).

Safety-critical sounds at job sites play an essential role in construction safety, but hearing capability is often declined due to the use of hearing protection and the complicated nature of construction noise. Thus, preserving or augmenting the auditory situational awareness of construction workers has become a critical need. To enable further advances in this area, it is necessary to synthesize the state-of-the-art auditory signal processing techniques and their implications for auditory situational awareness (ASA) and to identify future research needs. This paper presents a critical review of recent publications on acoustic signal processing techniques and suggests research gaps that merit further research for fully embracing construction workers' ASA of hazardous situations in construction. The results from the content analysis show that research on ASA in the context of construction safety is still in its early stage, with inadequate AI-based sound sensing methods available. Little research has been undertaken to augment individual construction workers in recognizing important signals that may be blocked or mixed with complex ambient noise. Further research on auditory situational awareness technology is needed to support detecting and separating important acoustic safety cues from complex ambient sounds. More work is also needed to incorporate context information into sound-based hazard detection and to investigate human factors affecting the collaboration between workers and AI assistants in sensing the safety cues of hazards.

Fernandez-Esquer, M. E., et al. (2020). "Documenting and Understanding Workplace Injuries Among Latino Day Laborers." J Health Care Poor Underserved 31(2): 791-809.

BACKGROUND: Latino day laborers face substantial injuries at work. We present a comprehensive assessment of their injury experience and explore the predictors of selfreported injuries. METHODS: Worker and injury characteristics were collected from 331 day laborers using an innnovative injury assessment tool. The odds of injury were estimated using a logistic regression. RESULTS: Participants were foreign-born, Spanish monolingual, and employed in construction. Sixty-seven individuals reported 88 past-year injuries, mostly involving the upper or lower extremities. Injuries were caused by moving heavy objects, falling, or being struck an object. Of the documented injuries, 24% were not reported at work due to fear of being fired; 64.4% resulted in missed workdays, 54.0% in temporary incapacitation, and 34.5% in permanent incapacitation. Being married significantly reduced the odds of reporting an injury. DISCUSSION: Better documentation can inform the development of better policy protections that ameliorate injuries experienced by Latino day laborers at the workplace.

Flynn, M. A. and J. M. Sampson (2012). "Trench Safety-Using a Qualitative Approach to Understand Barriers and Develop Strategies to Improve Trenching Practices." International Journal of Construction Education and Research 8(1): 63-79.

Despite efforts to ensure workplace safety and health, injuries and fatalities related to trenching and excavation remain alarmingly high in the construction industry. Because properly installed trenching protective systems can potentially reduce the significant number of trenching fatalities, there is clearly a need to identify the barriers to the use of these systems and to develop strategies to ensure these systems are utilized consistently. The current study reports on the results of focus groups with construction workers and safety management personnel to better understand these barriers and to identify solutions. The results suggest several factors, from poor planning to pressures from experienced workers and supervisors, which present barriers to safe trenching practices. Based on the results, it is recommended that safety trainings incorporate unique messages for new workers, experienced workers and management in an effort to motivate each group to work safely as well as provide them with solutions to overcome the identified barriers. © 2012 Taylor and Francis Group, LLC.

Gambatese, J. and F. Zhang (2016). "Impact of advisory signs on vehicle speeds in highway nighttime paving project work zones." Transportation Research Record 2555: 65-71.

Pavement preservation projects typically require construction workers to conduct their work in close proximity to ongoing traffic. During paving operations, workers are located within a protected work zone. Some are situated nearby or engaged with the equipment, while others may be a long distance from the equipment and on foot. The study reported here was conducted to investigate how temporary advisory speed signs located periodically in a work zone affected vehicle speeds within highway paving project work zones. The study used an experimental approach that involved a multilane paving project on a high-speed roadway in Oregon. The posted regulatory speed on the roadway was 65 mph, which was reduced temporarily to 50 mph in the work zone. During construction, 35 mph advisory signs were posted along with other traffic control devices (e.g., "Speed 50" signs with radar speed display and portable changeable message signs on rollers), and the impact they had on vehicle speed and speed variability was evaluated. The research findings indicated that use of the 35 mph signs led to lower vehicle speeds within the work zone. The reduction in speed was greater by passenger cars than by trucks. The use of 35 mph advisory signs in

work zones is recommended to help reduce vehicle speeds through the entire work zone and to minimize safety risks, especially to workers on foot and situated away from major equipment. © 2016, National Research Council. All rights reserved.

Gambatese, J. A. and S. Rajendran (2012). "Flagger illumination during nighttime construction and maintenance operations." Journal of Construction Engineering and Management 138(2): 250-257.

Ensuring the safety of flaggers, motorists, and workers is the primary consideration for flagging operations during nighttime construction and maintenance. A research study was conducted to evaluate four different types of light equipment-a light tower, 12 V spotlight, 12 V high-intensity discharge (HID) floodlight, and balloon lights-with regards to their level of illumination and uniformity over the flagging area and on the flagger's body. For each type of equipment, three input variables-lamp output, offset angle, and luminaire height-were varied to create a total of 44 different light equipment configurations. Each configuration was evaluated in terms of illumination, uniformity, and visibility in an urban/suburban setting. The study revealed that a light tower with 2,000 W output, 0 offset angle, and raised to a height of 20feet was the highest ranked type of equipment. However, when ease of use, mobility, and cost were added as output measures, a 12 V spotlight with 0 offset angle and raised to a height of 10feet received the highest ranking. Smaller light systems are easy to operate and transport, inexpensive, and more applicable for short-term flagging operations and for operations that need to be relocated frequently. Highly ranked configurations were typically those at 0 offset with luminaires elevated to 10feet or higher. Configurations with higher luminaire heights and lamp outputs from 250 to 2,000 W may perform better depending on the roadway setting, duration of flagging operation, and amount of artificial background lighting. © 2012 American Society of Civil Engineers.

Grant, A. and J. Hinze (2014). "Construction worker fatalities related to trusses: An analysis of the OSHA fatality and catastrophic incident database." Safety science 65: 54-62.

This study was conducted to gain a better understanding of the risks associated with truss installation in building projects. The Occupational Safety and Health Administration (OSHA) fatality and catastrophic incident database was analyzed for the years inclusive of 1990-2009. The database includes over 15,000 incidents, 211 of which pertain to trusses. The incidents were analyzed as to the number of fatalities per incident, the type of truss, the truss material, the activity taking place at the time of the accident, the release of the hoisting equipment, the initiation of the accident, the presence of bracing materials, the type of construction, the length of the trusses, the location of the incident, the type of accident (fall, caught-in/between, struck by, or electrocution), and the year the fatality occurred. Many of the accidents occurred at elevation and were initiated in large part by moving or falling objects. The study recommends that further research should focus on the stabilization of incomplete roof structures and the implementation of best practices for fall protection while performing truss-related work. © 2014 Elsevier Ltd.

Harris, E. B., et al. (2008). "Delayed femoral shaft fracture secondary to nail gun injury: a case report." J Orthop Trauma 22(7): 501-503.

Nail gun injuries are common workplace occurrences among construction workers; however, delayed fractures of the femur after a nail gun injury are not found in the medical literature. We report the case of a patient who presented with such a fracture 3 days after accidentally firing a nail into his thigh. The patient was taken to the operating room for intramedullary nailing, irrigation and debridement, and antibiotic beads. Standard postoperative hospital care was provided, and after 2

days of intravenous antibiotics, the patient was returned to the operating room for removal of the antibiotic beads and a delayed primary closure. At the most recent follow-up, over 1 year postinjury, he had radiographic healing and was asymptomatic. Although it is difficult to predict whether the stress riser created by a nail gun injury will lead to a fracture, weight-bearing status and the aggressiveness of treatment to prevent infection are factors that need to be carefully considered in patients with this type of injury.

Hassan, M. M., et al. (2010). "New Approach to Compare Glare and Light Characteristics of Conventional and Balloon Lighting Systems." Journal of Construction Engineering and Management 137(1): 39-44.

With the increasing needs to adopt nighttime construction strategies in order to avoid disruption of traffic flow, state agencies are currently experimenting with a new class of light towers known as balloon lights. Compared to regular lighting tower, balloon lights have been reported to reduce glare significantly and to provide more uniform lighting conditions at the site. The objective of this study was to measure light and glare characteristics of two balloon lighting systems in the field. Glare and lighting characteristics of this new class of light towers were compared to a conventional lighting system. For this purpose, field measurements were made of the pavement luminance and the horizontal and vertical illuminances on a predefined experimental grid. Results of this study indicated that while being comparable in terms of wattage and luminous flux, the tested balloon light systems differed in terms of light and glare characteristics. In addition, while conventional light tower provided greater illuminance at the light source than balloon lights, the disability glare was greater for conventional light tower than balloon lights when mounted at the same height. Results of this study revealed that optimum conditions should be sought in the work zone, through which adequate lighting conditions are provided for workers while disability glare is kept below a safe threshold for drive-by motorists. Plotting the maximum veiling luminance ratio (disability glare) against the workable distance provides a simple approach to consider the two factors concurrently in the design of work zone lighting.

Hinze, J. (2005). "Use of trench boxes for worker protection." Journal of Construction Engineering and Management 131(4): 494-500.

Safe work practices for the use of trench boxes identified by a survey of utility contractors are presented. Trench boxes are designed to protect workers from cave-ins, but human error and judgment can lead to unnecessary risks. The practices include the prevention of workers leaving the trench by the backfill and the provision of frequent training courses

Hinze, J. and G. Giang (2008). "Factors associated with construction worker eye injuries." Safety science 46(4): 634-645.

This paper reports on the results of a study of construction worker eye injuries collected by a firm that provides medical treatment services to over 40,000 construction workers each year. The records maintained by these clinics were examined for information related to injury causation and specific factors associated with construction worker eye injuries. A study was conducted on a random sample of a portion of the data involving construction workers eye injuries. The objective was to identify factors that were associated with eye injury causation. Over 600 eye injuries were examined. There was an equal distribution of right eye and left eye injuries. It was noted that for nearly 80% of the eye injuries, no eye protection was worn at the time of the injury. When dust particles were involved in the injury, no eye protection was worn in 97% of the instances. Specific patterns of

injuries were noted. For example, when grinding metal, 66% of the injuries were to the right eyes. Additionally, the use of drills was associated with significantly more right eye injuries, while the use of hammers was associated with significantly more left eye injuries. These findings suggest that right or left eye injuries are associated with certain tools and tasks, suggesting that additional research is warranted in this area. Eye protection is one means of reducing these types of injuries, but it appears that task layout and tool design may also have an influence.

Hinze, J., et al. (2005). "The nature of struck-by accidents." Journal of Construction Engineering and Management 131(2): 262-268.

Construction accidents are broadly categorized into five basic groups, namely falls (from elevation), shock (electrical), caught inibetween, struck-by, and other. 'Struck-by' accidents accounted for 22% of all construction-related fatalities recorded by the Occupational Safety and Health Administration between 1985 and 1989. Recent (1997 to 2000) data show that the percentage of struck-by accidents constituted 24.6% of the fatalities and serious construction worker injuries. Struck-by accidents primarily involve workers struck by equipment, private vehicles, falling materials, vertically hoisted materials, horizontally transported materials, and trench cave ins. Determining possible causation factors of these accident types is often difficult, due to the broad categories utilized in the accident coding system. This study resulted in gaining insights about the root causes of the struck-by injuries. By finding the root causes, effective methods for accident prevention can be developed

Hsiao, H., et al. (2008). "Effect of scaffold end frame carrying strategies on worker stepping response, postural stability, and perceived task difficulty." Hum Factors 50(1): 27-36.

OBJECTIVE: This study determined the most favorable strategy for carrying scaffold end frames while minimizing the risk of injuries from being struck by an object, falling, and overexertion. BACKGROUND: Scaffold erectors are at risk of high exposure to the aforementioned hazards associated with the dynamic human-scaffolding interface and work environments. Identifying an optimal work strategy can help reduce risk of injuries to the worker. METHOD: Three carrying methods, four types of work surfaces, two weights of scaffold frames, and three directions of stepping movement were tested in a laboratory with 18 construction workers. RESULTS: The effects of carrying method on postural instability and task difficulty rating were significant for handling the 22-kg end frame. Response time, postural instability, and perceived task difficulty rating were significantly reduced when the 9-kg end frame was used as compared with the 22-kg frame. CONCLUSION: The symmetric side-carrying method was the best option for handling 22-kg scaffold end frames. A 9-kg end frame (e.g., made of reinforced lightweight materials) has the potential to reduce injury risk among scaffold handlers during their scaffold erection and dismantlingjobs. APPLICATION: Scaffold erectors may want to adopt the symmetric side-carrying method as the primary technique for handling the 22-kg scaffold end frame, which is currently the one most used in the industry.

Jackson, S. A. and D. Loomis (2002). "Fatal occupational injuries in the North Carolina construction industry, 1978-1994." Appl Occup Environ Hyg 17(1): 27-33.

Occupational injury is a major public health problem and the cause of high rates of fatalities. The construction industry is one of the leading industries for on-the-job fatalities. The North Carolina Medical Examiner's system was used to identify all fatal unintentional injuries that occurred on the job in the state's construction industry between 1978 and 1994. The populations at risk were

estimated from the 1980 and 1990 U.S. censuses. There were 525 identified deaths. All except two decedents were male, and the majority were Caucasian (79.2%). The mean age of decedents was 39 years. Death rates were higher among older workers. The crude fatality rate for the overall study period was 15.4 per 100,000 worker-years, with higher rates found among African-Americans (22.9) than among Caucasians (14.5). Occupations within the industry with the highest rates were laborers (49.5), truck drivers (43.2), operating engineers (37.2), roofers (32.8), and electricians (29.0). Falls (26.7%), electrocutions (20.4%), and motor vehicle accidents (18.9%) were found to be the leading causes of death. These findings suggest a need for continued attention to the hazards of heights and electric currents and a need for occupational safety standards for motor vehicles. This study also suggests that the hazards facing construction laborers require further investigation.

Kazan, E. and M. A. Usmen (2018). "Worker safety and injury severity analysis of earthmoving equipment accidents." J Safety Res 65: 73-81.

INTRODUCTION: Research on construction worker safety associated with construction equipment has mostly focused on accident type rather than injury severity and the embedded factor relationships. Significant variables and their effects on the degree of injury are examined for earthmoving equipment using data from OSHA. Four types of equipment, backhoe, bulldozer, excavator, and scraper are included in the study. Accidents involving on-foot workers and equipment operators are investigated collectively, as well as separately. METHODS: Cross tabulation analysis was conducted to establish the associations between selected categorical variables, using degree of injury as a dichotomous dependent variable (fatal vs. nonfatal) and a number of independent variables having different values. Odds ratios were calculated to determine how much a certain variable/factor increases the odds of fatality in an accident, and the odds ratios were ranked to determine the relative impact of a given factor. RESULTS: It was found that twelve variables were significantly associated with injury severity. Rankings based on odds ratios showed that inadequate safety training (2.54), missing equipment protective system (2.38), being a non-union worker (2.26), being an equipment operator (1.93), and being on or around inadequately maintained equipment (1.58) produced higher odds for fatality. CONCLUSION: A majority of the earthmoving equipment accidents resulted in fatality. Backhoes were the most common equipment involved in accidents and fatalities. Struck-by accidents were the most prevalent and most fatal. Non-OSHA compliant safety training, missing seatbelt, operator not using seatbelt, malfunctioning back-up alarms, and poorly maintained equipment were factors contributing to accidents and fatalities. On-foot workers experienced a higher number of accidents than operators, while fatality odds were higher for the operators. Practical applications: Safety professionals should benefit from our findings in planning and delivering training and providing oversight to workers in earthmoving equipment operations.

Kica, J. and K. D. Rosenman (2014). "Surveillance for work-related skull fractures in Michigan." J Safety Res 51: 49-56.

Objectives: The objective was to develop a multisource surveillance system for work-related skull fractures. Methods: Records on work-related skull fractures were obtained from Michigan's 134 hospitals, Michigan's Workers' Compensation Agency and death certificates. Cases from the three sources were matched to eliminate duplicates from more than one source. Workplaces where the most severe injuries occurred were referred to OSHA for an enforcement inspection. Results: There were 318 work related skull fractures, not including facial fractures, between 2010 and 2012. In 2012, after the inclusion of facial fractures, 316 fractures were identified of which 218 (69%) were facial fractures. The Bureau of Labor Statistic's (BLS) 2012 estimate of skull fractures in Michigan,

which includes facial fractures, was 170, which was 53.8% of those identified from our review of medical records. The inclusion of facial fractures in the surveillance system increased the percentage of women identified from 15.4% to 31.2%, decreased severity (hospitalization went from 48.7% to 10.6% and loss of consciousness went from 56.5% to 17.8%), decreased falls from 48.2% to 27.6%, and increased assaults from 5.0% to 20.2%, shifted the most common industry from construction (13.3%) to health care and social assistance (15.0%) and the highest incidence rate from males 65 + (6.8 per 100,000) to young men, 20-24 years (9.6 per 100,000). Workplace inspections resulted in 45 violations and $62,750 in penalties. Conclusions: The Michigan multisource surveillance system of workplace injuries had two major advantages over the existing national system: (a) workplace investigations were initiated hazards identified and safety changes implemented at the facilities where the injuries occurred; and (b) a more accurate count was derived, with 86% more work-related skull fractures identified than BLS's employer based estimate. Practical Applications: A more comprehensive system to identify and target interventions for workplace injuries was implemented using hospital and emergency department medical records. © 2014 Elsevier Ltd.

Konda, S., et al. (2020). "Workers' compensation claims for traumatic brain injuries among private employers-Ohio, 2001-2011." Am J Ind Med 63(2): 156-169.

BACKGROUND: The purpose of this analysis was to identify and prioritize high-risk industry groups for traumatic brain injury (TBI) prevention efforts. METHODS: Workers with TBI from 2001 to 2011 were identified from the Ohio Bureau of Workers' Compensation data. To prioritize industry groups by claim type (lost-time (>/=8 days away from work) and total claims) and injury event categories, we used a prevention index (PI) that averaged TBI counts and rate ranks (PI = (count rank + rate rank)/2). TBI rates per 10 000 estimated full-time equivalent (FTE = 2000 h/y) workers were calculated. RESULTS: From 2001 to 2011, 12 891 TBIs were identified among private employers, resulting in a rate of 5.1 TBIs per 10 000 FTEs. Of these, 40% (n = 5171) were lost-time TBIs, at a rate of 2.0 per 10 000 FTEs. Spectator Sports had the highest lost-time TBI rate (13.5 per 10 000 FTEs), whereas General Freight Trucking had the greatest number of lost-time TBIs (n = 293). Based on PIs, General Freight Trucking ranked first for lost-time TBIs for all injury events combined. Several industry groups within Construction, General and Specialized Freight Trucking, Services to Building and Dwellings, Employment Services, and Restaurants and Other Eating Places ranked high across multiple injury event categories for lost-time TBIs. CONCLUSIONS: The high-ranking industry groups identified from our study can be used to effectively direct occupational TBI prevention efforts.

Lipscomb, H. (2010). "Knowledge and Recommendations of Sales Personnel Regarding Pneumatic Nail Gun Safety (CPWR Report)."

In this small project we collected data from points of sale or rental of framing nail guns to document knowledge of staff regarding the safety mechanisms on the tools they sell or rent and their recommendations for use. Less than 25% (24.4%) of sales/rental personnel mentioned any differences in triggers on the tools and of those who did, 60% of that group described the differences correctly. Overall, 29% correctly described the trigger differences including personnel who had to be directly asked. Less than half (40.6%) of the personnel we talked with provided us with any safety information about the tools

Lipscomb, H. J., et al. (2010). "Perspectives of residential contractors on nail gun safety." New Solut 20(3): 337-348.

Perspectives on nail gun safety were sought from residential contractors as part of an injury surveillance and prevention effort (2005-2008). Anonymous surveys inquired about tool use, training, injury risk, and awareness of the 2003 American National Standards Institute (ANSI) standard calling for shipment of pneumatic nail guns used in wood framing with sequential actuation. Despite some awareness of inexperience, lack of training, speed and tool design in injury causation, 55 percent consistently reported injuries resulted from worker carelessness. Contractors reported safety experiences of their employees were considerably better than those of other residential contractors. After five years, only 16 percent reported any awareness of the voluntary standard. These findings raise questions as to what gains can realistically be expected from passage of voluntary standards such as the one described here. Given that the epidemiology of acute injuries from pneumatic nail guns is now well-described, the safer sequential trigger should be required to protect workers.

Lipscomb, H. J., et al. (2015). "Musculoskeletal concerns do not justify failure to use safer sequential trigger to prevent acute nail gun injuries." Am J Ind Med 58(4): 422-427.

Background: Acute nail gun injuries can be controlled significantly by using tools with sequential triggers and training. Concern has been raised that sequential triggers, which require that the nose piece of the gun be depressed prior to pulling the trigger, could increase risk of musculoskeletal problems. Methods: We conducted active injury surveillance among union carpenter apprentices to monitor acute injuries and musculoskeletal disorders between 2010 and 2013. Results: Acute injury risk was 70% higher with contact trip rather than sequential triggers. Musculoskeletal risk was comparable (contact trip 0.09/10,000hr (95% CI, 0.02-0.26); sequential 0.08/ 10,000hr (95% CI 0.02-0.23)). Conclusions: Concern about excess risk of musculoskeletal problems from nail guns with sequential triggers is unwarranted. Both actuation systems carry comparable musculoskeletal risk which is far less than the risk of acute injury; there is clearly no justification for failure to prevent acute injuries through use of the safer sequential trigger. Am. J. Ind. Med. 58:422-427, 2015. © 2015 Wiley Periodicals, Inc.

Lipscomb, H. J., et al. (2008). "Prevention of traumatic nail gun injuries in apprentice carpenters: use of population-based measures to monitor intervention effectiveness." Am J Ind Med 51(10): 719-727.

INTRODUCTION: Nail guns are responsible for a significant injury burden in residential construction. Risk, based on hours of work, is particularly high among apprentice carpenters due in part to more frequent exposure to tool use. METHODS: Nail gun injuries were evaluated over 3 years among carpenters enrolled in two apprenticeship programs in the Midwest (2.3 million residential work hours observed) following initiation of training and a voluntary ANSI standard change calling for safer sequential triggers on framing nailers. Injury rates, based on hours of tool use, were calculated yearly. Rates and adjusted rate ratios were calculated with Poisson regression. Attributable risk percent (AR%) and population attributable risk (PAR%) were calculated yearly for modifiable independent risk factors for injury including lack of training in tool use and type of trigger mechanism on tools being used. RESULTS: As apprentices received training and safer trigger mechanisms became more widespread, injury rates decreased significantly (31%). While school training and hands-on mentoring were both important, injury rates were lowest among apprentices who received both. Although injury rates changed over the observation period, the relative risk comparing trigger mechanisms did not; contact trip triggers consistently carried a twofold risk. CONCLUSIONS: Although training and safer trigger use both increased, because of the relative prevalence of training and trigger exposures in this population, the engineering solution consistently

had the potential to make more difference in population risk. Our findings demonstrate the utility of observational methods including measures of population-based risk in monitoring intervention effectiveness and making recommendations that lead to injury reduction.

Lipscomb, H. J., et al. (2010). "Continued progress in the prevention of nail gun injuries among apprentice carpenters: what will it take to see wider spread injury reductions?" J Safety Res 41(3): 241-245.

PROBLEM: Nail guns are a common source of acute, and potentially serious, injury in residential construction. METHOD: Data on nail gun injuries, hours worked and hours of tool use were collected in 2008 from union apprentice carpenters (n=464) through classroom surveys; this completed four years of serial cross-sectional data collection from apprentices. A predictive model of injury risk was constructed using Poisson regression. RESULTS: Injury rates declined 55% from baseline measures in 2005 with early training and increased use of tools with sequential actuation. Injury rates declined among users of tools with both actuation systems, but the rates of injury were consistently twice as high among those using tools with contact trip triggers. DISCUSSION AND IMPACT: Nail gun injuries can be reduced markedly through early training and use of tools with sequential actuation. These successful efforts need to be diffused broadly, including to the non-union sector.

Lipscomb, H. J., et al. (2011). "Buyer beware: personnel selling nail guns know little about dangerous tools." Am J Ind Med 54(8): 571-578.

BACKGROUND: Nail gun use is ubiquitous in wood frame construction. Accessibility and decreasing costs have extended associated occupational hazards to consumers. Compelling evidence documents decreased injury risk among trained users and those with tools with sequential triggers. To prevent inadvertent discharge of nails, this safer trigger requires the nose be depressed before the trigger is pulled to fire. The sequential trigger is not required by the Consumer Product Safety Commission (CPSC) or the Occupational Safety and Health Administration (OSHA) nor are there any guidelines for training. METHODS: We collected data from personnel at 217 points of sale/rental of framing nail guns in four areas of the country. RESULTS: Sales personnel had little understanding of risks associated with use of framing nail guns. Individuals who had used the tool and those working in construction outlets were more likely to be knowledgeable; even so, less than half understood differences in trigger/actuation systems. CONCLUSIONS: Consumers, including contractors purchasing for workers, cannot count on receiving accurate information from sales personnel regarding risks associated with use of these tools. The attitudes and limited knowledge of some sales personnel regarding these potentially deadly tools likely contributes to a culture accepting of injury. The findings demonstrate how influences on the culture of construction are not limited to workers, employers, or the places construction gets done.

Lipscomb, H. J., et al. (2008). "How much time is safety worth? A comparison of trigger configurations on pneumatic nail guns in residential framing." Public Health Rep 123(4): 481-486.

OBJECTIVE: Nail gun injuries are among the most common in wood frame construction. Despite evidence that the majority of injuries from unintentional firings could be prevented with a sequential trigger mechanism on the tools, the safer trigger has not been embraced in the fast-paced residential construction industry. An experiment was conducted in an attempt to realistically evaluate the magnitude of productivity concerns. METHODS: Ten journeymen carpenters built a yard shed on two occasions, using nail guns with two different trigger configurations, alternately, under controlled

conditions. Mean differences in time required, nails used, and proper placement were evaluated considering the trigger used and whether the building was the carpenter's first or second project. RESULTS: The sequential trigger tool required a mean of 10 additional minutes of active nailing time, which represented 10% of mean nailing time (97 minutes) but only 0.77% of the total mean work time (1,298 minutes) to construct each shed. No significant differences were observed in nail count or placement. The majority of the time variability was related to who was using the tool, rather than the type of tool in the person's hand. CONCLUSIONS: Productivity concerns should focus more on improving the skill of the carpenter rather than on the trigger mechanism. Failure to place tools with the safer trigger configuration, which requires the nose piece to be depressed before the trigger is pulled, in the hands of workers does not make sense given the frequency and potential repercussions of injuries associated with the use of these tools in wood framing.

Lipscomb, H. J. and A. L. Schoenfisch (2015). "Nail gun injuries treated in U.S emergency departments, 2006-2011: not just a worker safety issue." Am J Ind Med 58(8): 880-885.

BACKGROUND: Nail guns increase productivity in residential building but with a corresponding increase in worker injuries. They are also easily accessible, at low cost, to consumers. METHODS: Data from the occupational supplement to the National Electronic Injury Surveillance System (NEISS-Work) were used to calculate national estimates of work-related injuries from nail guns between 2006 and 2011. These were compared to estimates of consumer injuries obtained through online access to the Consumer Product Safety Commission's (CPSC) NEISS data. RESULTS: Approximately 25,000 ED-treated work-related and consumer nail gun injuries were estimated each year. During the construction economy collapse, injuries among workers declined markedly, closely following patterns of reduced residential employment. Reduction in consumer injuries was much more modest. CONCLUSIONS: Current nail gun injury patterns suggest marked blurring of work and home exposures. A united effort of CPSC, NIOSH, and OSHA is warranted to address these preventable injuries.

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Lipscomb, H. J., et al. (2010). "Non-fatal contact injuries among workers in the construction industry treated in U.S. emergency departments, 1998-2005." J Safety Res 41(3): 191-195.

PROBLEM: The National Occupational Research Agenda (NORA) for the construction industry calls for efforts to identify areas where guidance and regulation are needed to adequately

prevent traumatic injuries resulting from a worker coming into contact with objects or equipment. METHOD: This descriptive study of work-related contact injuries in the construction industry that were treated in emergency departments (EDs) between 1998 and 2005 utilized records of work injuries captured through a national probability-based sample of U.S. hospitals with 24-hour ED services. RESULTS: Contact injuries accounted for 54% of all construction ED-treated injuries. Hospitalizations were most common for injuries from contact with discharged nails from pneumatic nail guns, with hand held power saws, and fixed saws. Some injuries were proportionally more serious and sometimes involved multiple workers including trenching injuries and those resulting from collapse of buildings under construction, walls, roofs, and scaffolding. DISCUSSION AND IMPACT: Given that nail gun use is limited primarily to wood frame construction, efforts are needed to control frequent serious injuries associated with these tools. Enforcement of existing trenching regulations is also needed.

Lipscomb, H. J., et al. (2010). "Nonfatal tool- or equipment-related injuries treated in US emergency departments among workers in the construction industry, 1998-2005." Am J Ind Med 53(6): 581-587.

BACKGROUND: Individuals in the construction industry are exposed to a variety of tools and pieces of equipment as they work. METHODS: Data from the National Institute for Occupational Safety and Health (NIOSH) occupational supplement to the National Electronic Injury Surveillance System (NEISS-Work) were used to characterize tool- and equipment-related injuries among workers in the construction industry that were treated in US emergency departments between 1998 and 2005. Based on a national stratified probability sample of US hospitals with 24 hr emergency services, NEISS-Work allows calculation of national injury estimates. RESULTS: Over the 8-year period between 1998 and 2005, we estimated 786,900 (95% CI 546,600-1,027,200) ED-treated tool- or equipment-related injuries identified by the primary or secondary source of injury code. These injuries accounted for a quarter of all ED-treated construction industry injuries. Although over 100 different tools or pieces of equipment were responsible for these injuries, seven were responsible for over 65% of the injury burden: ladders, nail guns, power saws, hammers, knives, power drills, and welding tools in decreasing order. CONCLUSIONS: Current injury estimates and their severity, marked by the proportion of cases that were not released after ED treatment, indicate interventions are particularly needed to prevent injuries associated with use of ladders as well as nail guns and power saws. Attention should focus on design and guarding to more efficiently prevent these injuries rather than simply calling for the training of workers in how to safely use a dangerous tool or piece of equipment.

Lombardi, D. A., et al. (2005). "Welding related occupational eye injuries: a narrative analysis." Inj Prev 11(3): 174-179.

OBJECTIVE: To determine the activities and circumstances proximal to a welding related occupational eye injury, a hybrid narrative coding approach derived from two well developed classification systems was developed to categorize and describe the activity, initiating process, mechanism of injury, object and/or substance, and the use of protective eyewear from the narrative text data reported for each injury. METHODS: Routinely collected workers' compensation claims over a one year period (2000) were analyzed from a large US insurance provider. An index term search algorithm of occupation, incident, and injury description fields identified 2209 potential welding related eye injury claims. After detailed review of these claims, 1353 welders and 822 non-welders were analyzed. RESULTS: During 2000, eye(s) as the primary injured body part accounted for 5% (n = 26 413) of all compensation claims. Eye injuries accounted for 25% of all claims for

welders. Subjects were mainly male (97.1%) and from manufacturing (70.4%), service (11.8%), or construction (8.4%) related industries. Most injuries were foreign body (71.7%) or burn (22.2%) and 17.6% were bilateral. Common activities include welding (31.9%) and/or grinding (22.5%). Being struck by an airborne object occurred in 56.3% of cases. Non-welders showed similar patterns except that burns (43.8%) were more frequent and more often initiated by another worker (13.9%). CONCLUSIONS: Narrative injury text provides valuable data to supplement traditional epidemiologic analyses. Workers performing welding tasks or working nearby welders should be trained to recognize potential hazards and the effective use of proper safety equipment to prevent ocular injury.

Marks, E. D., et al. (2013). "Laser scanning for safe equipment design that increases operator visibility by measuring blind spots." Journal of Construction Engineering and Management 139(8): 1006-1014.

One-fourth of construction industry fatalities are caused by worker collisions with construction equipment. Nonvisible areas (blind spots) for equipment operators are contributing factors to many of these fatalities because equipment operators are unable to see ground personnel at certain locations around their equipment. Presented are the design and validation of a unique technique for measuring blind spots by using laser scanning data. The work demonstrates how the design of construction equipment impacts the visibility of its operator. The contribution of the developed technique to the body of knowledge is that it can precisely evaluate and compare different equipment models and design characteristics. The blind spot measurement data for several similar pieces of equipment provides design suggestions that increase operator visibility. By increasing operator visibility through advanced equipment design, safety can be promoted on construction sites and in any other work environment, particularly with nearby ground workforce equipment.

Marks, E. D. and J. Teizer (2013). "Method for testing proximity detection and alert technology for safe construction equipment operation." Construction Management and Economics 31(6): 636-646.

The US construction industry continues to be among the leading industries for workplace fatalities after experiencing 818 fatalities in 2009. Approximately 21% of these fatalities resulted from workers being struck by an object or piece of construction equipment. The nature of construction sites often produces hazardous conditions by requiring ground workers and heavy construction equipment to operate in close proximity. The primary objective is to present a method for testing proximity detection and alert systems. Experimental trials were designed to deploy emerging radio frequency (RF) remote sensing technology to demonstrate the ability of the test method to evaluate the capability of proximity detection and alert systems to provide alerts when heavy construction equipment and workers are in too close proximity to each other. Numerous field experiments were designed and conducted to emulate typical interactions between workers on foot and construction equipment. These devices were installed on pieces of construction equipment in an outdoor environment to evaluate the test method for proximity detection and alert systems. Experimental results show that proximity detection and alert technologies can provide alerts to equipment operators at different pre-calibrated proximity alert ranges. The results suggest that the presented testing method adequately evaluated the reliability and effectiveness of the proximity detection and alert technology in the construction environment. © 2013 Taylor and Francis Group, LLC.

Marsh, S. M. and D. E. Fosbroke (2015). "Trends of occupational fatalities involving machines, United States, 1992-2010." Am J Ind Med 58(11): 1160-1173.

BACKGROUND: This paper describes trends of occupational machine-related fatalities from 1992-2010. We examine temporal patterns by worker demographics, machine types (e.g., stationary, mobile), and industries. METHODS: We analyzed fatalities from Census of Fatal Occupational Injuries data provided by the Bureau of Labor Statistics to the National Institute for Occupational Safety and Health. We used injury source to identify machine-related incidents and Poisson regression to assess trends over the 19-year period. RESULTS: There was an average annual decrease of 2.8% in overall machine-related fatality rates from 1992 through 2010. Mobile machine-related fatality rates decreased an average of 2.6% annually and stationary machine-related rates decreased an average of 3.5% annually. Groups that continued to be at high risk included older workers; self-employed; and workers in agriculture/forestry/fishing, construction, and mining. CONCLUSION: Addressing dangers posed by tractors, excavators, and other mobile machines needs to continue. High-risk worker groups should receive targeted information on machine safety.

McCall, B. P. and I. B. Horwitz (2006). "Assessment of occupational eye injury risk and severity: an analysis of Rhode Island workers' compensation data 1998-2002." Am J Ind Med 49(1): 45-53.

BACKGROUND: Occupational eye injuries have been recognized as a serious health risk to workers and are in need of further investigation to develop effective interventions. METHODS: Rhode Island workers' compensation claims of ocular injury between 1998 through 2002 (n=8,877) were examined. The Current Population Survey was used to estimate occupational employment levels as a baseline for rate calculations. RESULTS: The estimated ocular injury claim rate was 32.9 per 10,000 workers (95% CI=32.3-33.6), with the cost of claims totaling $1,514,666 and averaging $171 per claim. The highest estimated claim rate of all occupations was found for construction laborers of 373.7 per 10,000 workers (95% CI=267.1-480.3). Relative to the durable manufacturing industry, the highest risk of injury resulting in disability indemnification was the wholesale trade industry (OR=2.18, 95% CI=1.19-4.01, P<0.05). CONCLUSIONS: Many of the eye injuries reported were likely preventable. Greater diligence, training, and safety precautions are needed to reduce the risk of eye injury to employees.

McCall, B. P., et al. (2009). "Occupational eye injury and risk reduction: Kentucky workers' compensation claim analysis 1994-2003." Inj Prev 15(3): 176-182.

BACKGROUND: Occupational eye injuries are a significant source of injury in the workplace. Little population-based research in the area has been conducted, and is necessary for developing and prioritizing effective interventions. METHODS: Workers' compensation data from the state of Kentucky for the years 1994-2003 were analysed by demographics, injury nature and cause, cost, and occupational and industrial characteristics. The US Bureau of Labor Statistics' Current Population Survey was utilised to compute injury rates for demographic and occupational groups. RESULTS: There were 10,545 claims of ocular injury, representing 6.29 claims per 10,000 workers on average annually. A substantial drop in the claim rate was found after the state passed monetary penalties for injuries caused by employer negligence or OSHA violations. Claims by men were over three times more likely than those by women to have associated claim costs (OR 0.52; 95% CI 0.32 to 0.85; p = 0.009). The highest eye injury rates per 10,000 of 13.46 (95% CI 12.86 to 14.07) were found for the helpers/labourers occupation, and of 19.95 (95% CI 18.73 to 21.17) for the construction industry. The total cost of claim payments over the period was over $3,480,000, and average cost per claim approximated $331. CONCLUSIONS: Eye injuries remain a significant risk

to worker health, especially among men in jobs requiring intensive manual labour. Evidence showed that increased legislative regulation led to a decline in eye injuries, which was consistent with other recent findings in the area. Additionally, targeting groups most at risk, increasing worker training, providing effective eye protection equipment, and developing workplace safety cultures may together reduce occupational eye injuries.

McCann, M. (2006). "Heavy equipment and truck-related deaths on excavation work sites." J Safety Res 37(5): 511-517.

PROBLEM: Contact with objects and equipment is the third leading cause of death in construction. This study examines heavy equipment- and truck-related deaths in the excavation work industry in construction. METHODS: The Bureau of Labor Statistics Census of Fatal Occupational Injuries identified 253 heavy equipment related deaths on construction sites in the Excavation Work industry for the years 1992-2002. RESULTS: Heavy equipment operators and construction laborers made up 63% of the heavy equipment- and truck-related deaths. Backhoes and trucks were involved in half the deaths. Rollovers were the main cause of death of heavy equipment operators. For workers on foot and maintenance workers, being struck by heavy equipment or trucks (especially while backing up for workers on foot), and being struck by equipment loads or parts were the major causes of death. DISCUSSION: Ensuring adequate rollover protective structures for heavy equipment, requiring fastening of seat belts, adoption of a lock-out/tagout standard, establishing restricted access zones around heavy equipment, and requiring spotters for workers who must be near heavy equipment or trucks would reduce the risk of heavy equipment- and truck-related deaths in construction. IMPACT ON INDUSTRY: Safety of heavy equipment operators in particular is a major concern in excavation that needs to be addressed.

McCann, M. and M. T. Cheng (2012). "Dump truck-related deaths in construction, 1992-2007." Am J Ind Med 55(5): 450-457.

BACKGROUND: Dump trucks are universally used in construction and other industries to haul materials to the location and to remove waste materials. METHODS: The source for dump truck-related fatality data was the Bureau of Labor Statistics Census of Fatal Occupational Injuries (CFOI) Research File. RESULTS: From 1992 to 2007, 829 construction workers were killed in dump truck-related incidents nationwide. Of those, 336 were dump truck operators with 215 deaths occurring in street and highway incidents. Another 343 deaths involved workers on foot, three-quarters struck by dump trucks. Sixty-four of the construction workers killed were maintaining dump trucks, 22 when caught between the truck frame and a falling dump truck bed. Of the 86 other deaths, 55 involved streets and highways. CONCLUSIONS: Recommendations include: (i) improving the reporting of seat belt usage in fatality reports; (ii) requiring use of seat belts; (iii) requiring the use of backup alarms, spotters, or other methods to alert dump truck operators to workers in their blind spots; (iv) prohibiting direct dumping at river banks and embankments; (v) using cameras or radar to enforce stopping at railway crossings; and (xi) enforcing worker safety practices (e.g., lockout/tagout procedures on elevated dump truck beds).

McMullin, N. and J. Queen (2004). "A construction worker with recent confusion, disorientation, and somnolence." Cleve Clin J Med 71(10): 809-814.

Worker struck in the head by falling object reported confusion, somnolence.

Mekker, M. M., et al. (2016). "Variable speed limit study upstream of an Indiana work zone with vehicle matching." Transportation Research Record 2555: 53-64.

Traffic management in work zones presents significant mobility and safety challenges for agencies. The goals of a work zone traffic management plan are to safely slow vehicles ahead of the work zone, maintain speeds that provide for the safety of motorists and construction workers, and manage the growth of queues. Historically, variable speed limits (VSLs) have been presented as a form of technology that can dynamically regulate speed in response to prevailing traffic conditions. However, techniques used to evaluate the impact of VSLs typically use aggregated statistics such as mean and standard deviation to determine the typical speed reduction. This paper presents a new methodology to evaluate the impact of VSL signage on the basis of individual vehicle matching. The speeds and speed changes of these matched vehicles were used to analyze individual driver response to the VSLs. This approach allows agencies to understand the impact that VSL signage has on the distribution of vehicle speeds. It was concluded that vehicles would need to observe multiple signs before any tangible reduction in speed limit would occur. The new vehicle-matching methodology showed that, after drivers observed a 15-mph drop in the speed limit for cars (10 mph for trucks) on three consecutive VSL signs, they reduced their speed by a median of 7.5 mph (5.8 mph for trucks). Overall, 4% of cars and 10% of trucks complied with the 55-mph speed limit after the observance of three VSL signs. © 2016, National Research Council. All rights reserved.

Mohan, S. and W. C. Zech (2005). "Characteristics of worker accidents on NYSDOT construction projects." J Safety Res 36(4): 353-360.

INTRODUCTION: This paper aims at providing cost-effective safety measures to protect construction workers in highway work zones, based on real data. Two types of accidents that occur in work zones were: (a) construction work area accidents, and (b) traffic accidents involving construction worker(s). METHODOLOGY/RESULTS: A detailed analysis of work zone accidents involving 36 fatalities and 3,055 severe injuries to construction workers on New York State Department of Transportation (NYSDOT) construction projects from 1990 to 2001 established that five accident types: (a) Struck/Pinned by Large Equipment, (b) Trip or Fall (elevated), (c) Contact w/Electrical or Gas Utility, (d) Struck-by Moving/Falling Load, and (e) Crane/Lift Device Failure accounted for nearly 96% of the fatal accidents, nearly 63% of the hospital-level injury accidents, and nearly 91% of the total costs. These construction work area accidents had a total cost of $133.8 million. Traffic accidents that involve contractors' employees were also examined. Statistical analyses of the traffic accidents established that five traffic accident types: (a) Work Space Intrusion, (b) Worker Struck-by Vehicle Inside Work Space, (c) Flagger Struck-by Vehicle, (d) Worker Struck-by Vehicle Entering/Exiting Work Space, and (e) Construction Equipment Struck-by Vehicle Inside Work Space accounted for nearly 86% of the fatal, nearly 70% of the hospital-level injury and minor injury traffic accidents, and $45.4 million (79.4%) of the total traffic accident costs. CONCLUSIONS: The results of this paper provide real statistics on construction worker related accidents reported on construction work zones. Potential preventions based on real statistics have also been suggested. IMPACT ON INDUSTRY: The ranking of accident types, both within the work area as well as in traffic, will guide the heavy highway contractor and owner agencies in identifying the most cost effective safety preventions.

Nadesan, K. (2000). "A fatal nail gun injury--an unusual ricochet?" Med Sci Law 40(1): 83-87.

An 18-year-old construction worker suddenly collapsed while handling a power-actuated nail gun and died shortly after. A neat, almost circular puncture wound was found on the front of his left

chest. No fire-arm residues were detected on the surrounding skin. The police stated that it was an accidental injury, at a construction site, where a nail fired from a nail gun by the deceased had deflected off the wall and struck him on the front of the chest. Since the entry wound appeared to be a neat hole, and that too on the front of the left chest overlying the heart area, there was reluctance on the part of the pathologist to accept it as an accidental injury due to a ricochet. A visit to the scene, interrogation of witnesses, examination of the alleged tool and post-mortem X-ray of the deceased were undertaken prior to autopsy. A bent nail was found in the heart. The scene visit and the subsequent autopsy revealed that the nail took a roughly circular flightpath after it had struck the wall, all the while travelling with its pointed end directed forward. Within the body too, the nail maintained the same path. Various medicolegal issues are discussed pertaining to nail-gun injuries. The importance of a visit to the scene, examination of the alleged tool, interrogation of witnesses and the X-ray of the body, all prior to autopsy, are emphasized. The conclusion was: accidental death due to the unusual ricochet of a nail.

Nahmens, I. and L. H. Ikuma (2012). "Effects of lean construction on sustainability of modular homebuilding." Journal of Architectural Engineering 18(2): 155-163.

Construction activities and the built environment have an enormous effect on the environment, human health, and the overall economy. Sustainable homebuilding in all three dimensions of economic, environmental, and social effects is attainable through practical innovations and technologies. However, the greatest barrier to the widespread application of sustainable homebuilding is the higher initial costs largely attributable to the learning curve of workers building with these practical innovations and technologies, and the added cost resulting from ill-defined construction processes. To address these challenges and reach the ideal of sustainable construction, this paper proposes the use of lean construction as a viable and effective strategy, in particular the lean tool kaizen. This paper uses several case studies to showcase the effect of lean on the triple bottom line of sustainability in modular homebuilding. Each case study highlights one dimension of sustainability. Lean construction resulted in a significant environmental effect by reducing material waste by 64%, a significant social effect by reducing or eliminating key safety hazards of excessive force, poor posture, and struck-by, and a significant economic effect by reducing production hours by 31%. Findings from this research will contribute to a better understanding of the effect of lean on homebuilding sustainability and will promote lean and safe building techniques in modular homebuilding. © 2012 American Society of Civil Engineers.

Nasrollahzadeh, A. A., et al. (2021). "Identifying factors associated with roadside work zone collisions using machine learning techniques." Accid Anal Prev 158: 106203.

Identifying factors that are associated with the probability of roadside work zone collisions enables decision makers to better assess and control the risk of scheduling a particular maintenance or construction activity by modifying the characteristics of the operation. This can be achieved by studying the effect of work zone properties on the risk of roadside work zone collisions. Much of the existing work in this area is based on data in the police traffic collision reports, which do not include data on the characteristics of the work zone itself. This paper develops a comprehensive data set of 42 features describing time, location, work zone characteristics, traffic volume, and road properties. Using recent machine learning techniques such as extreme gradient boosting classifiers on this extensive set of features allows for more accurate analysis to identify factors that affect the risk of work zone collisions or indicate higher than baseline chances of a roadside crash. Our statistical

analysis reveals 10 important features and shows that four of these features are significantly associated with higher probabilities of roadside work zone collisions.

Odeh, I., et al. (2009). "Field experiments to evaluate and control light tower glare in nighttime work zones." Journal of Construction Engineering and Management 135(9): 911-919.

An increasing volume of highway repair and construction work is being performed during the off-peak nighttime hours to mitigate the impact of construction-related daytime traffic congestions and shorten the duration of construction operations. The utilization and placement of light towers to illuminate the work zone in this type of construction can cause harmful levels of glare for both drivers and construction workers. This paper presents the results of field experiments which were conducted to (1) study the levels of glare and lighting performance generated by light towers in and around nighttime work zones; (2) analyze the combined impact of the light tower set up parameters including its height as well as its aiming and rotation angles on glare and lighting performance; and (3) provide practical recommendations to reduce and control lighting glare in and around nighttime work zones. The results of these experiments confirm that the set up of light towers has a significant impact on glare and therefore it should be carefully designed and executed on nighttime highway construction projects to ensure the safety of the traveling public as well as construction workers.

Pan, C. S., et al. (2020). "An Approach to Characterize the Impact Absorption Performance of Construction Helmets in Top Impact." J Test Eval 49(3).

The helmets used by construction site workers are mainly designed for head protection when objects are dropped from heights. Construction helmets are also casually called "hard hats" in industries. Common construction helmets are mostly categorized as type 1 according to different standards. All type 1 helmets have to pass type 1 standard impact tests, which are top impact tests-the helmet is fixed and is impacted by a free falling impactor on the top crown of the helmet shell. The purpose of this study was to develop an approach that can determine the performance characterization of a helmet. A total of 31 drop impact tests using a representative type 1 helmet model were performed at drop heights from 0.30 to 2.23 m, which were estimated to result in impact speeds from 2.4 to 6.6 m/s. Based on our results, we identified a critical drop height that was used to evaluate the performance of helmets. The peak impact forces and peak accelerations varied nonproportionally with the drop height. When the drop height is less than the critical height, the peak force and peak acceleration increase gradually and slowly with increasing drop height. When the drop height is greater than the critical height, the peak force and peak acceleration increase steeply with even a slight increase in drop height. Based on the critical drop height, we proposed an approach to determine the safety margin of a helmet. The proposed approach would make it possible to determine the performance characteristics of a helmet and to estimate the safety margin afforded by the helmet, if the helmet first passes the existing standardized tests. The proposed test approach would provide supplementary information for consumers to make knowledgeable decisions when selecting construction helmets.

Park, J., et al. (2016). "Performance test of wireless technologies for personnel and equipment proximity sensing in work zones." Journal of Construction Engineering and Management 142(1).

The dynamic nature and limited work space of roadway work zones contribute to dangerous working environments for construction workers. This environment can result in hazardous proximity situations because pedestrian workers are required to operate in close proximity to heavy construction equipment. A total of 609 work zone personnel fatalities were reported in 2012.

Previous analysis of work zone fatality data found that the majority of the pedestrian worker and mobile object struck-by fatalities resulted when pedestrian workers were struck by construction equipment. These statistics indicate that current safety practices for pedestrian workers and equipment operators are inadequate. The objective of this study was to create and evaluate a proximity detection and alert system using Bluetooth sensing technology. The scope included hazardous proximity situations between pedestrian workers and construction equipment in roadway work zones at grade. Evaluation metrics were implemented to assess the tested proximity sensing systems including the cost, time and ease of calibration, required hardware, system capabilities, and many others. Commercially available radio frequency identification (RFID) and magnetic field proximity sensing systems were also evaluated to provide a basis for comparison. Various interaction scenarios between pedestrian workers and construction equipment were used in the evaluation of the system. The performance evaluation based on the statistical results showed that all the tested systems were considered reliable with minimal false alarm rates. However, the magnetic system showed a significant drop in its coverage range, while still providing reliable coverage measures, with a set of tests that were more dynamic than other sets of tests. The created Bluetooth system provided the highest level of simplicity with its minimized infrastructure, ease of calibration, and ease of installation. In sum, experimental results demonstrate that the created proximity detection and alert system (1) requires minimal infrastructure; (2) provides adequate alerts to equipment operators and pedestrian workers; and (3) provides, through an alert, an additional layer of hazard avoidance in real time during hazardous-proximity situations in roadway work zones. © 2015 American Society of Civil Engineers.

Pi, Y., et al. (2023). "Lane-specific speed analysis in urban work zones with computer vision." Traffic Inj Prev 24(3): 242-250.

OBJECTIVE: Work zone speed is one of the most important factors in road construction safety management. This work presents a computer vision based technique designed to measure lane-specific individual vehicle speed using existing traffic monitoring cameras and computers. The resulted speeds support the influence analysis of factors including traffic control, lane positions, and construction activity. METHODS: Object detection (YOLOv5) and tracking (Deep-SORT) algorithms are combined to track the vehicles. In particular, 21 days' worth of road construction videos are collected from a pole-mounted traffic monitoring camera operated by the Texas A&M University Transportation Services. Based on the object detection results, a novel construction activity inference technique is developed to approximate the times when construction workers are present. Based on this time separation, the vehicle speeds with and without the presence of construction activity are compared. RESULTS: The proposed framework is able to measure speeds with an error ranging from 0 to 6.4 kilometers per hour (KPH). Detailed analysis of this video data suggests that traffic control with barrels in the median work zone lowers the average speed (for all vehicles) by 15 KPH. The lane adjacent to the work zone also has higher speed variation than the other lanes. The construction activity speed comparisons show when the traffic is slow (possibly traffic after a red light), the difference is statistically significant with a p-value ranging from 0.01 to 0.03. When the traffic is fast (possibly traffic encountering a green signal as they approached the nearby intersection) construction activity has no significant effect on the work zone speeds. CONCLUSIONS: The proposed CV technique is a reliable and cheap method to measure lane-specific work zone speeds. The derived measurements support detailed safety analysis. Other than work zone speeds, the proposed technique can also be used for regular traffic speed monitoring.

Plog, B., et al. (2006). "Strategies to Prevent Trenching-Related Injuries and Deaths (CPWR Report)."

Prahlow, J. A., et al. (2020). "Elevator-Related Deaths." J Forensic Sci 65(3): 823-832.

Elevators are mechanical transportation devices used to move vertically between different levels of a building. When first developed, elevators lacked the safety features. When safety mechanisms were developed, elevators became a common feature of multistory buildings. Despite their well-regarded safety record, elevators are not without the potential for danger of injury or death. Persons at-risk for elevator-related death include maintenance and construction workers, other employees, and those who are prone to risky behavior. Deaths may be related to asphyxia, blunt force, avulsion injuries, and various forms of environmental trauma. In this review, we report on 48 elevator-related deaths that occurred in nine different medicolegal death investigation jurisdictions within the United States over an approximately 30-year period. The data represents a cross-section of the different types of elevator-related deaths that may be encountered. The review also presents an overview of preventive strategies for the purpose of avoiding future elevator-related fatalities.

Ravani, B. and C. Wang (2018). "Speeding in highway work zone: An Evaluation of methods of speed control." Accid Anal Prev 113: 202-212.

Highway workers frequently work in close proximity of live traffic in highway work zones, traffic accidents therefore have devastating effects on worker safety. In order to reduce the potential for such accidents, methods involving use of advisory signs and police presence have been used to mitigate accident risks and improve safety for highway workers. This research evaluates the magnitude of the speeding problem in highway work zones and the effects of four levels of police presence on improving work zone safety. Speed data were collected in six different work zone locations in northern and southern California and used to determine the magnitude and nature of speeding problem in highway work zones. In addition data were collected over 11 test-days in four work zones with four levels of police presence: radar speed display with police decal and lighting, passive use of a police vehicle with radar speed display, passive use of a police vehicle without radar speed display, and active police speed enforcement near work zones. This paper analyzes this data using statistical methods to evaluate the effectiveness of these different methods of speed control on the safety of the work zone. Four Measures of Effectiveness (MOE) were used in this evaluation consisting of average speed reduction, speed variance, 85th percentile speed, and proportion of high speed vehicles. The results indicate that all levels of police presence provided statistically significant improvements in one or more of the MOEs.

Ray, S. J. and J. Teizer (2012). "Coarse head pose estimation of construction equipment operators to formulate dynamic blind spots." Advanced Engineering Informatics 26(1): 117-130.

Several hundred workers die in construction in the United States every year because equipment operators are unable to see their fellow workers during operation of their vehicle. In this paper we propose a step towards improving this situation by providing an automated method based on range imaging for estimating the coarse head orientation of a construction equipment operator. This research utilizes commercially-available low resolution range cameras to measure the continuously changing field-of-view (FOV) of an equipment operator in outdoor construction. This paper presents a methodology to measure so-called dynamic blind spot maps. The dynamic blind spot map is then projected on a known static equipment blind spot map that already exists to each construction vehicle. A robust computational coarse head pose estimation algorithm and results to

three different pieces of construction equipment and multiple operators are presented. The developed method has the potential in automatically determining the spaces around vehicles that are currently not in the field-of-view of the vehicle operator thus providing eventually additional means and technology for improving safety in construction. © 2011 Elsevier Ltd. All rights reserved.

Ray, S. J. and J. Teizer (2013). "Computing 3D blind spots of construction equipment: Implementation and evaluation of an automated measurement and visualization method utilizing range point cloud data." Automation in Construction 36: 95-107.

Limited visibility due to blind spots of construction equipment was responsible for 55% of the visibility-related fatalities in the construction industry. Knowledge of blind spot aids in improving safety on construction sites and the design of equipment cabin itself. Existing approaches for blind spot measurement that follow international standards typically require a time-consuming set-up and are limited by the number of different visibility analyses that can be performed. A new approach to compute blind spot in a fast and efficient way using point cloud data of equipment is presented. The developed approach allows performing different analyses such as: volumetric blind spots, blind spot map, 12 m circumference visibility, rectangular 1 m boundary visibility, and worker visibility. In addition, the above set of analyses can be performed from different viewpoints located virtually anywhere inside the equipment cabin. Validating against synthetic "noisy" point clouds, robustness and accuracy of the approach is established.

Sakhakarmi, S. and J. Park (2022). "Improved intrusion accident management using haptic signals in roadway work zone." J Safety Res 80: 320-329.

INTRODUCTION: Roadway work zones are known for hazard vulnerability, with many injuries and fatalities each year, due mostly to intrusions. Despite several available measures to improve safety, existing mechanisms are unreliable for workers to perceive alerts, due to the harsh working environment, with loud noise and limited vision. This research attempts to overcome hazard perception difficulties by introducing a new communication mechanism for intrusion hazard perception. METHOD: The presented communication mechanism is based on past tactile sensing research, and is enhanced by signal profile and message modeling investigations. Experimental field trials were conducted for mechanism evaluation with a goal of improved situational awareness through tactile sensing. RESULTS: The trial results show that users perceive warning messages well, even when their vision and hearing are limited, and that the signalized messages perceived could augment users' understanding of a potential hazard, allowing immediate precautionary actions. Practical Applications: The application of haptic signals in vulnerable work zones has the potential to improve upon limitations in innate sensing (e.g., vision and hearing), thus presenting an opportunity to better protect workers from potential accidents.

Sakhakarmi, S., et al. (2021). "Tactile-based wearable system for improved hazard perception of worker and equipment collision." Automation in Construction 125: 103613.

Although past studies investigated automated hazard-identification methods, few explored workers' awareness capabilities for detected hazards. Recent research identified that workers have difficulty becoming aware of potential risks in harsh construction environments (limited vision and hearing). In response, this study investigated a new communication method with a wearable tactile-based system to improve worker's hazard perception. Built on past research, we identified key informational details to represent detected safety hazards, developed a tactile-based communication mechanism, and conducted a series of field trials. Results were assessed to determine the system's

reliability with respect to several scenarios, conducted in a controlled environment for safety reasons. Test results demonstrated that the system is capable of alerting workers of pre-identified collision hazards without relying on their innate sensing (hearing and vision). Findings could help workers to become aware of detected hazards in harsh environments, where it is difficult to hear alerts or spot potential hazards.

Schoenfisch, A. L., et al. (2013). "Work-related injuries among union drywall carpenters in Washington State, 1989-2008." Am J Ind Med 56(10): 1137-1148.

BACKGROUND: Drywall installers are at high-risk of work-related injury. Comprehensive descriptive epidemiology of injuries among drywall installers, particularly over time, is lacking. METHODS: We identified worker-hours and reported and accepted workers' compensation (WC) claims for a 20-year (1989-2008) cohort of 24,830 Washington State union carpenters. Stratified by predominant type of work (drywall installation, other carpentry), work-related injury rates were examined over calendar time and by worker characteristics. Expert interviews provided contextual details. RESULTS: Drywall installers' injury rates, higher than those of other carpenters, declined substantially over this period by 73.6%. Common injury mechanisms were struck by/against, overexertion and falls. Drywall material was considered a contributing factor in 19.7% of injuries. One-third of these drywall material-related injuries resulted in paid lost time, compared to 19.4% of injuries from other sources. Rates of injury were particularly high among workers with 2 to <4 years in the union. Notable declines over time in rates of overexertion injury in which drywall material was a contributing factor were still observed after controlling for secular temporal trends. Experts highlighted changes over the past 20 years that improved both work safety and, in some cases, production. CONCLUSIONS: Declines in drywall installers' injury rates over time likely reflect, in part, enhanced workplace safety, including efforts to reduce overexertion hazards associated with handling drywall. Continued injury prevention efforts are needed, particularly for less tenured workers. Given the potential for under-reporting to WC, additional sources of health outcomes data may provide a more complete picture of workers' health.

Sheikh, N. M., et al. (2010). "Application of precast concrete barrier adjacent to steep roadside slope." Transportation Research Record: 121-129.

When concrete barriers are installed adjacent to drop-offs or steep roadside slopes such as 1.5H:1V, a cast-in-place concrete moment slab is usually attached to the base of the barrier to resist lateral and overturning forces during vehicle impact. Cast-in-place construction can require more time on-site to build forms, pour the concrete, and allow for curing. This time constraint results in an increase in disruption to traffic and more exposure for construction workers. Furthermore, the installation of a moment slab is very costly and requires an additional construction phase to build the slab. Because the slab is normally under the shoulder and possibly the lanes, the disruption of traffic flow is increased. A new application of a precast 42-in.-tall single-slope concrete barrier for use in front of steep slopes was developed that does not require a moment slab. The lateral movement of the barrier is restricted by embedding it in soil. This design also reduces the embankment behind the barrier to 2 ft. The embedded barrier application was successfully evaluated under Manual for Assessing Safety Hardware Test Level 3 criteria. The permanent deflection of the barrier was 5.5 in. The use of the embedded concrete barrier in lieu of the typically installed barrier with a moment slab is expected to result in cost savings of approximately $300 per linear foot and reduced time to construct.

Shen, X., et al. (2016). "Hazardous Proximity Zone Design for Heavy Construction Excavation Equipment." Journal of Construction Engineering and Management 142(6): 05016001.

The construction industry continues to be among the leading industries for workplace fatalities in the United States. After experiencing 824 fatal injuries in 2013, the construction industry ranks as one of the most dangerous work environments when compared with other private industrial sectors in the United States. Conditions of construction sites often produce hazardous proximity situations by requiring pedestrian workers and heavy equipment to operate at close proximity. Injury and fatality statistics indicate that current safety practices of construction workers have proven inadequate. The research aims to design hazard zone around pieces of heavy construction equipment in which site personnel should not enter during construction operations. The scope is limited to construction sites and equipment at a horizontal grade and hazards between heavy construction excavation equipment and workers-on-foot. A framework for creating the hazard zone around a piece of construction equipment is presented including detailed methodology discussions for each step. A user interface is also presented that automatically creates a hazard zone around select pieces of construction equipment based on user-defined parameters. The hazard zone for a dump truck, excavator, and backhoe are shown using the created framework. Results indicate that hazard zones for pedestrian workers can be created around construction equipment to increase hazard awareness for workers. Contributions for this research include a user-friendly hazard zone creation tool and database for safety managers and scientific evaluation data of the created hazard zone framework. Safety standards can be formulated based on the design and implement hazard zones on equipment.

Shrestha, P. P., et al. (2018). "Types and factors affecting injury rates of mechanical contractors." Work 61(1): 135-148.

BACKGROUND: In the United States, about 38,000 cases of nonfatal workplace injuries were reported in 2015, in the category of 'mechanical work' (plumbing, heating, and air conditioning); this is nearly identical to the number of cases reported under 'building construction'. OBJECTIVE: This paper analyzes the types and rates of injuries and illnesses of mechanical contractors of southern Nevada, including the nature of the injuries and illnesses, body parts affected by injuries, causes of injuries, and factors affecting the injury rates. METHODS: To obtain data, a survey consisting of questions regarding the number of injuries and types of injuries was conducted with 31 mechanical contractors of southern Nevada involved in plumbing, piping, heating, refrigeration, and air conditioning. RESULTS: The injury rate for larger mechanical contractors (n = 16), in terms of number of employees and annual revenue, was significantly lower than for smaller mechanical contractors (n = 15). Mechanical contractors who worked on residential buildings (n = 13) had significantly higher rates of injuries than those involved with industrial (n = 7) or commercial buildings (n = 10). Results showed that sprains and strains (31%) were dominant injuries, and the major causes were from parts and materials (39%), hand tools (16%), contact with objects (14%), and falls (7%). CONCLUSIONS: The study concluded that the injury rate for these mechanical contractors was found to be higher than that reported by the Occupational Safety and Health Administration for specialty trade contractors.

Sinyai, C. and S. Choi (2020). "Fifteen years of American construction occupational safety and health research." Safety science 131: 104915.

The researchers reviewed construction occupational safety and health research published in high-impact, peer-reviewed academic journals between 2002 and 2016 to assess whether research in the field is efficiently targeted to produce evidence-based interventions addressing the industry’s

most serious occupational hazards. Unlike most previous surveys of the field, this interdisciplinary literature search captured research published in the construction management and engineering literature as well as that in public health and medicine journals. The researchers found 741 articles by US-based lead authors, with falls the most-studied safety hazard (89 articles) and airborne silica exposure the most-studied health hazard (51), both among the deadliest current hazards in construction occupational safety and health, but much asbestos research was sponsored by companies involved in litigation, generating few findings useful for protecting today's workers. The review described important trends in the literature, including increased attention to noise and hearing loss, a growing number of intervention studies, and greater concern for populations at disproportionate risk (e.g., small/residential, Latino/immigrant, younger/older workers, & women working in construction). The National Institute for Occupational Safety and Health (NIOSH) directly or indirectly funded a majority of the published research. Policymakers should understand that most occupational safety and health research depends on NIOSH funding.

Sun, C., et al. (2012). "Safety evaluation of sequential warning lights in tapers at nighttime work zones." Transportation Research Record: 1-8.

Safety improvement at nighttime work zones is important because of visibility concerns after dark. The deployment of sequential lights is an innovative method to improve driver recognition of lane closures and work zone tapers. Sequential lights are wireless warning lights that flash in a sequence to delineate clearly the taper at work zones. The effectiveness of sequential lights was investigated with the use of controlled field studies. Traffic parameters were collected at the same field site with and without the deployment of sequential lights. Three surrogate performance measures (the speeds of approaching vehicles, the number of late taper merges, and the locations where vehicles merged into an open lane from a closed lane) were used to determine the impact of sequential lights on safety. The results of this study showed that sequential warning lights had a net positive effect: the warning lights reduced the speeds of approaching vehicles and enhanced driver compliance, and the lights shifted overall merge behavior upstream. Statistically significant decreases of 3.56 km/h (2.21 mph) mean speed and 1.61 km/h (1 mph) 85% speed resulted with sequential lights. The shift in the cumulative speed distributions to the left (i.e., speed decrease) was found to be statistically significant with the Kolmogorov-Smirnov test. With sequential lights, there was a statistically significant increase of 1.47 km/h (0.91 mph) in the speed standard deviation, and the percentage of vehicles that merged earlier increased from 53.49% to 65.36%.

Tayabji, S., et al. (2012). "Joint load transfer and support considerations for jointed precast concrete pavements." Transportation Research Record: 74-80.

Many agencies recently have started investigating strategies for pavement rehabilitation and reconstruction that are faster to implement and can produce longer-lasting pavements than previous strategies. Most highway agencies no longer consider expedient rehabilitation that results in a shorter pavement lifespan acceptable. One promising alternative rehabilitation strategy is the effective use of modular pavement technologies, principally precast concrete pavement (PCP) systems, which provide for the rapid repair and rehabilitation of pavements and also result in durable, long-lasting pavements. Rapid construction techniques can significantly minimize the impact on the driving public because lane closures and traffic congestion are minimized. Road user and worker safety also are improved by reduced road users' and workers' exposure to construction traffic. The renewal focus area under Strategic Highway Research Program 2 (SHRP 2) emphasizes the need to complete highway pavement projects rapidly, with minimal disruption to highway users and local

communities, and to produce pavements that are long lasting. One goal of this focus area includes applying new methods and materials to preserve, rehabilitate, and reconstruct roadways. The effective use of PCP technologies for rapid repair, rehabilitation, and reconstruction of pavements addresses this goal. One of the projects funded under SHRP 2 is Project R05, Modular Pavement Technology. The objective of Project R05 was to develop better guidance for use by highway agencies to design, construct, install, maintain, and evaluate modular pavement systems, principally PCP systems. Findings related to joint load transfer and support considerations for jointed PCP from the Project R05 study are presented.

Teizer, J., et al. (2010). "Autonomous pro-active real-time construction worker and equipment operator proximity safety alert system." Automation in Construction 19(5): 630-640.

Over six hundred construction worker deaths occurred in the United States during the inclusive years of 2004 to 2006 that were related to construction equipment and contact collisions. This paper presents findings about emerging radio frequency (RF) remote sensing and actuating technology that can improve construction safety by warning or alerting workers-on-foot and equipment operators in a pro-active real-time mode once equipment gets too close in proximity to unknown or other equipment. A review is provided on the background and importance of safety related to various pieces of construction equipment. Pro-active real-time proximity and alert technology for daily construction operations is introduced to solve this problem. Results of various field experiments that tested the proximity and alert technology are presented. A discussion follows on how such technology can improve objective construction site safety data collection and lead to more effective construction workforce safety training and education. © 2009 Elsevier B.V. All rights reserved.

Theiss, L., et al. (2011). "Merging taper lengths for lane closures of short duration." Transportation Research Record: 64-70.

The merging taper lengths described in the Manual on Uniform Traffic Control Devices are assumed to apply to roadways of all types. Yet driver expectations and traffic operations differ greatly between the high-speed freeway and the lower-speed, signalized urban street. The research described in this paper investigated the operational impacts of reduced taper lengths on lower-speed urban arterials. The study found that drivers did react differently after merging taper lengths were modified. Both the merging taper and the work vehicle in the closed lane served as visual cues to drivers to vacate the closed lane. On longer taper lengths, channelizing devices were used to motivate drivers to change lanes. Vehicles with occluded views, however, were more likely to become trapped and to create mobility issues in the traffic stream. On shorter taper lengths, drivers reacted to the merging taper and the work vehicle itself. Although fewer vehicles became trapped near the merge point, that point was much closer to the work vehicle. Under the absence of taper conditions (i.e., mobile operations), in which the work vehicle was much larger than the trucks used during the merging taper observations, fewer drivers remained in the closed lane at comparable locations. Both motorist and worker safety must be considered in the selection of an appropriate merging taper length for work activities of shorter duration on urban arterials. Further research should investigate the implications for worker safety of installing and removing various merging taper lengths as compared with the time it takes to complete the work activity.

Tiesman, H. M., et al. (2011). "The epidemiology of fatal occupational traumatic brain injury in the U.S." Am J Prev Med 41(1): 61-67.

BACKGROUND: Although traumatic brain injury (TBI) is one of the leading causes of death and disability in the U.S., work-related TBI has not been well documented. PURPOSE: The aim of this study was to describe the epidemiologic characteristics and temporal trends of fatal occupational TBI in the U.S between 2003 and 2008. METHODS: A cross-sectional analysis of the Census of Fatal Occupational Injury database was performed. Both the Occupational Injury and Illness Classification System nature of injury codes and body part codes were used to define TBIs. Fatality rates were calculated using denominators derived from the Current Population Survey. Fatality rates were compared among industries, cause of death, and demographics with rate ratios (RRs) and 95% CIs. Poisson regression was used to assess trends in fatality rates. Data were analyzed in 2009-2010. RESULTS: Nearly 7300 occupational TBI deaths occurred between 2003 and 2008, for an average fatality rate of 0.8 per 100,000 workers per year. The leading causes of occupational TBI death were as follows: motor vehicle (31%); falls (29%); assaults and violent acts (20%); and contact with objects/equipment (18%). Fatality rates were 15 times higher in men compared with women (RR=15, 95% CI=13.7, 16.3). Workers aged >/=65 years experienced the highest TBI fatality rate of all age groups (2.5 per 100,000 per year). Construction, transportation, and agriculture/forestry/fishing industries recorded nearly half of all TBI fatalities (n=1828, n=825, n=761, respectively). Occupational TBI death rates declined 23% over the 6-year period (p<0.0001). CONCLUSIONS: This study provides the first national profile of fatal TBIs occurring in the U.S. workplace. Prevention efforts should be directed at those industries with the highest frequency and/or highest risk. The construction industry had the highest number of TBIs, and the agriculture, forestry, and fishing industry had the highest rates. Additionally, workers aged >65 years in all industries would be a good target for future prevention efforts.

Vosbikian, M. M., et al. (2017). "The Impact of Safety Regulations on the Incidence of Upper-Extremity Power Saw Injuries in the United States." Journal of Hand Surgery 42(4): 296.e291-296.e210.

Purpose Over 50,000 power saw-related injuries occur annually in the United States. Numerous safety measures have been implemented to protect the users of these tools. This study was designed to determine which interventions, if any, have had a positive impact on the safety of the consumer or laborer. Methods We queried the National Electronic Injury Surveillance System database for hand and upper-extremity injuries attributed to power saws from 1997 to 2014. Demographic information including age, sex, date of injury, device, location, body part involved, diagnosis, and disposition was recorded. We performed statistical analysis using interrupted time series analysis to evaluate the incidence of injury with respect to specific safety guidelines as well as temporal trends including patients' age. Results An 18% increase in power saw–related injuries was noted from 1997 (44,877) to 2005 (75,037). From 2006 to 2015 an annual decrease of 5.8% was observed. This was correlated with regulations for power saw use by the Consumer Safety Product Commission (CPSC) and Underwriters Laboratories. Mean age of injured patients increased from 48.8 to 52.9 years whereas the proportion of subjects aged less than 50 years decreased from 52.8% to 41.9%. These trends were most pronounced after the 2006 CPSC regulations. Conclusions The incidence of power saw injuries increased from 1997 to 2005, with a subsequent decrease from 2006 to 2015. The guidelines for safer operation and improvements in equipment, mandated by the CPSC and Underwriters Laboratories, appeared to have been successful in precipitating a decrease in the incidence of power saw injuries to the upper extremity, particularly in the younger population. Clinical relevance The publication of safety regulations has been noted to have an association with a decreased incidence in power saw injuries. Based on this, clinicians should take an active role in

their practice as well as in their professional societies to educate and counsel patients to prevent further injury. © 2017 American Society for Surgery of the Hand

Welch, L. S., et al. (2001). "Injury surveillance in construction: eye injuries." Appl Occup Environ Hyg 16(7): 755-762.

Occupational eye injuries are both common and preventable. About 20% of occupational eye injuries occur in construction. To investigate the nature of eye injuries among construction workers, we analyzed a large data set of construction worker injuries. In addition, we interviewed 62 workers with eye injuries to further explore circumstances of eye injury and workers' attitudes and behavior toward the use of eye protection. Eleven percent (363 cases) of the 3,390 construction workers in our data set were treated for eye injuries. Welders, plumbers, insulators, painters/glaziers, supervisors, and electricians had a higher proportion of all injuries due to eye injuries than other trades. Nearly half of the diagnoses were abrasions (46%) followed by foreign objects or splash in the eye (29%), conjunctivitis (10%), and burns (5%). In the interviews with 62 workers, we found that employers very frequently required eye protection for all tasks or for high-risk tasks, and workers report wearing eye protection regularly. However, most did not wear eye protection with top and side shields; if we believe the injuries occurred because a particle or liquid passed between the glasses and the workers' faces, increased use of goggles or full shields would have prevented two-thirds of this group of injuries.

Welch, L. S., et al. (2005). "Occupational injuries among construction workers treated in a major metropolitan emergency department in the United States." Scand J Work Environ Health 31 Suppl 2: 11-21.

OBJECTIVES: The aim of this study was to profile construction workers' injuries for more information about the causes of nonfatal construction worker injuries and identify injury trends for further investigations and prevention programs. METHODS: An injury-tracking program for emergency departments was established in 1990 to gather the data needed for the study. Profiles were obtained for 2916 construction workers' injuries that were identified on hospital registration forms at the George Washington University Emergency Department in Washington, DC, from November 1990 through October 1997. Laborers and construction workers who did not specify a trade were combined, and together they made up the largest group--29% of the injured workers. RESULTS: The leading cause of injury was contact with cutting or piercing objects-most often pieces of metal, razors, knives, power tools, and nails. Workers striking against objects or being struck by objects (including falling objects) accounted for the second-largest group of injuries, and the third leading injury circumstance was falling--either from a height or on the same level. Detailed injury statistics are presented by trade, showing patterns of injury that reflect tasks of these trades and which injuries predominated in each trade. Although many previous reports have described construction workers' injuries, very few have provided detailed data by trade. CONCLUSIONS: The details presented in this analysis allow for a better understanding of the injury circumstances and provide a starting point for injury prevention programs.

Welton, M., et al. (2020). "Construction employment mortality among Mexican immigrants in the South Eastern United States, 2003-2013." International Journal of Migration, Health and Social Care 16(4): 349-358.

Purpose The purpose of this study was to investigate occupational and non-occupational mortality among Mexican immigrants in the South Eastern United States. The construction industry

has the highest burden of occupational fatalities in the USA of all industries, and foreign-born Hispanic workers are disproportionately affected. Design/methodology/approach Data were obtained from 3,093 death certificates maintained by the Consulate General of Mexico in Atlanta, Georgia. Standardized mortality ratios (SMR) were used to compare occupational-related deaths among construction industry occupations, and logistic regression models were used to examine the relationship between manners of death not related to occupation and employment in the construction industry. Findings The proportion of Mexican immigrants who died from occupational injuries is higher among all construction workers (SMR = 1.31), roofers (SMR = 2.32) and carpenters (SMR = 2.25) than other workers. Among the population in this analysis suicide [adjusted odds ratio (aOR) = 0.63] and death from natural causes (aOR = 0.70) were inversely related to work in the construction industry. Research limitations/implications Interventions to reduce occupational fatalities among Mexican migrant construction workers should target roofers and carpenters. Future research should further investigate the industry's association with suicide and natural death. Originality/value This is one of the first analyzes that investigated associations between construction industry employment and non-occupational fatalities among immigrants. The analysis provides evidence that a large portion of the Mexican immigrant population is used in the construction industry (38%) and face elevated risks for occupational fatalities and the results of this investigation should encourage greater surveillance of occupational illness and injury among foreign-born immigrants who work in construction, as well as other high-risk industries.

Yadav, N., et al. (2022). "On-Body Placement of Wearable Safety Promotion Devices Based on Wireless Communication for Construction Workers-on-Foot: State-of-the-Art Review." Sensors (Basel) 22(9).

High auditory noise levels and limited visibility are often considered among the main factors that hinder seamless communication on construction sites. Many previous research studies have leveraged technology to overcome these obstacles and communicate using the hearing, sight and touch senses. However, the technological efficacy does not secure the users' perceptivity of the wireless communication devices. Statistical data regarding the number of fatal accidents on construction sites have remained steady despite regular efforts. This study analyzed prior research on wearable safety promotion devices for personnel that move around the jobsite on foot. A seven-point checklist was utilized to shortlist prior studies (2005-2021) attempting to provide safety information wirelessly to the construction workers-on-foot. The reasoning behind various on-body placements was investigated along with the information conveyed using the three communication modalities. A novel communication network is also introduced to visualize the technical details. Lastly, limitations and future recommendations have been presented to gain insights about the factors that might affect the placement of the wearable safety promotion devices.

Yang, L., et al. (2021). "Assessing disabling and non-disabling injuries and illnesses using accepted workers compensation claims data to prioritize industries of high risk for Oregon young workers." J Safety Res 77: 241-254.

INTRODUCTION: Young workers are especially vulnerable to occupational injuries and illnesses. There is a continued need to investigate injury burden among young workers across demographics and industry to inform targeted interventions. Workers compensation (WC) claims are important for quantifying work-related injuries and illnesses, however published studies have focused on disabling claims. This study extended previous research on Oregon young workers by including the most recent WC claims data to identify patterns of injury and high risk industries.

METHODS: We obtained all accepted disabling claims (N = 13,360) and a significant portion of non-disabling claims (N = 24,660) on workers aged 24 years and under from 2013 to 2018. Claim count, rate and cost were calculated by year, age, gender, industry, and injury type. A prevention index (PI) method was used to rank industries in order to inform prevention efforts. RESULTS: Average annual disabling and non-disabling claim rates were 111.6 and 401.3 per 10,000 young workers. Workers aged 19-21 (disabling: 119.0 per 10,000 and non-disabling: 429.3) and 22-24 years (115.7 and 396.4) and male workers (145.3 and 509.0) had higher claim rates than workers aged 14-18 (80.6 and 297.0) and female workers (79.8 and 282.9). The most frequent injury types were "struck by/against" (35.6%) and "work-related musculoskeletal disorders (WMSDs)" (19.5%). High risk industries included agriculture, construction, and manufacturing for both genders combined. For female young workers, the highest risk industry was healthcare. CONCLUSIONS: This study demonstrated the added value of non-disabling WC claims data. Using both disabling and non-disabling data and PI method, agriculture, construction, manufacturing and healthcare industries were identified as priority workplaces to prevent common and costly injuries among Oregon young workers. Practical Applications: While the industries identified are considered hazardous for all workers, findings in this study can guide targeted research and prevention efforts specific to young workers.

Yuan, C., et al. (2016). "Vision-based excavator detection and tracking using hybrid kinematic shapes and key nodes." Journal of Computing in Civil Engineering 31(1).

Enhancing workplace safety continues to be a major task in the construction industry. Approximately 75% of struck-by fatalities are caused by inappropriate spatial-temporal relationships between construction workers and heavy equipment. Construction safety can be improved if the location and movement of heavy equipment are tracked in real time. However, detecting and tracking heavy equipment with kinematic joints and changing poses, such as excavators, is still a challenge for vision-based sensing methods. This study proposes to detect and track excavators using stereo cameras based on hybrid kinematic shape and key node features. Specifically, templates of excavator components are synthesized for detection following kinematic constraints of each component. Thereafter, a fast directional chamfer matching algorithm is used to detect the excavator components, and the detected components are articulated at the key nodes. Finally, the three-dimensional positions of the key nodes are tracked through triangulation to depict the excavator movements. Results from field experiments demonstrated that concatenating the detected components following a matching order enhances the detection performance. It is also found that the stereo triangulation enables efficient tracking of excavator movements by targeting at the key nodes. © 2016 American Society of Civil Engineers.

Zhang, F. and J. A. Gambatese (2017). "Highway Construction Work-Zone Safety: Effectiveness of Traffic-Control Devices." Practice Periodical on Structural Design and Construction 22(4).

Pavement preservation is a proactive approach to maintaining existing highways. Freeway-preservation projects typically require construction workers to conduct their work in close proximity to ongoing high-speed traffic. This exposure creates a dangerous situation for both workers and passing motorists. A recent study funded by the Oregon Department of Transportation (ODOT) implemented and evaluated different types of traffic-control devices on highway-preservation projects to reduce vehicle speeds and create safer work zones. The study implemented combinations of multiple traffic-control devices [speed-limit ("Speed 50") signs, portable changeable message signs (PCMSs), and radar speed displays] in two case study projects and evaluated their effects on

vehicle speed. The researchers used fixed-location sensors and probe vehicle runs to collect data on traffic speed. The results indicate that using a combination of PCMSs and radar speed displays is the best choice. Although data from the probe vehicle runs could not be used for statistical analysis because of limitations on the number of runs conducted, the data provide a vivid and direct view of how individual motorists behave in a construction work zone. The study also provides valuable insight into the effectiveness of the traffic-control measures that contractors can use to design safety into their work operations and further improve the safety in work zones. © 2017 American Society of Civil Engineers.

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