Identification of Safety Hazards in Highway Construction Projects

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ABSTRACT

Despite a global emphasis on safety, construction personnel experience a sizable number of occupational injuries. The dynamic nature of construction sites makes it extremely challenging to completely eliminate the hazards associated with these injuries, but an awareness of them and acknowledgement of their potential dangers are crucial first steps in improving the safety of the workers. This paper's goal is to add to the construction safety body of knowledge by conducting a thorough literature review and identifying, defining, and categorizing the safety hazards that affect the transportation sector of the construction industry. Through a literature review, fourteen (14) construction highway safety hazards were identified and categorized as primary, physical, chemical, and ergonomic or other, and based upon how often they were mentioned in the literature, working at heights, material and equipment handling, and heavy machinery appear to be the most hazardous to workers' safety. Recognizing the hazards, taking preventative measures, and implementing best practices for managing them are vital to improving worker safety and reducing the severity of injuries when they do occur. The results of this study will help employers in the construction industry detect potential safety hazards and lower the likelihood that highway workers will sustain occupational accidents and injuries from them.

Keywords: construction safety; hazard identification; highway safety; safety hazards; occupational injuries; hazard management

INTRODUCTION

Construction workers represent a relatively small portion of the workforce in the United States, yet they account for 20% of all non-fatal and 9% of all fatal occupational injuries (Karakhan and Gambatese 2018; Naiman et al. 2022). Highway construction and maintenance is uniquely dangerous due to workers' exposure to both on-site hazards and oncoming traffic. The Federal Highway Administration reported that about 3% of overall annual workplace fatalities are attributed to roadway construction (Nnaji et al. 2020a). Moreover, statistics have shown that a work zone fatality occurs approximately every 9 hours and a non-fatal injury occurs every 9 minutes (Nnaji et al. 2018). This is largely due to the frequent movement and interaction of personnel, materials, and equipment in a complex and ever-changing environment, which increases the possibility that safety hazards are disregarded.

Vitharana et al. (2015) defined a hazard as anything that has the potential to cause harm to an individual or have a negative impact on their health. The first step in managing or controlling

any hazard, regardless of the type, is to recognize it. Ideally, hazards are identified in the preconstruction stage to minimize the likelihood of their causing an accident (Mihić 2020); however, hazards should continue to be identified after the preconstruction stage and during all project stages (Alizadehsalehi et al. 2018). After identifying the hazards, a plan to eliminate, decrease or control them must be developed and implemented (Pamidimukkala and Kermanshachi 2022). Hazard identification is considered to be the most useful safety management tool available to construction managers, and numerous studies have highlighted its significance (Jeelani et al. 2017), as unidentified construction safety hazards worsen injury severity and cost the industry billions of dollars annually (Kermanshachi and Safapour 2019; Sanni-Anibire et al. 2020). The belief that the risks are low, inexperience, a failure to notice the danger, or personal risk-taking habits can all contribute to poor hazard recognition (Jeelani et al. 2017). The inherent risks associated with each of the four construction industry sectors vary greatly (residential, commercial, industrial, and highway) and are also dependent on project complexity (Kermanshachi et al. 2020; Kermanshachi et al. 2023), making it more difficult to identify them and leaving workers vulnerable to a wide range of injuries. Therefore, a comprehensive exploration of the hazards specifically impacting highway construction personnel is necessary.

Within the construction safety body of knowledge, hazards have been extensively studied (Alizadehsalehi et al. 2018; Sanni-Anibire et al. 2020; Pamidimukkala et al. 2022). Because of the numerous existing safety hazard studies that have been done and the variety of themes they cover, it can be difficult for stakeholders to have a comprehensive understanding of this subject. Thus, to provide a structured and comprehensive overview of highway construction safety hazards, a thorough evaluation of previous research is imperative. Moreover, several studies have concentrated on a single or small number of safety hazards rather than thoroughly discussing all the hazards that could exist on construction sites. Anantharaman et al. (2023) assessed the injury patterns and contributing factors associated with falls from heights, whereas Vukadinovic and Radosavljevic (2020) investigated extreme temperatures as a potential hazard in construction. These studies, however, do not provide a thorough discussion of every hazard that could arise during transportation projects.

Due to variability in construction project types and work environments, the research on highway safety hazards is sparse. Various authors have explored the topic of highway construction safety (Kim et al. 2013; Nnaji et al. 2018; Li et al. 2018; Nnaji et al. 2020a). Nevertheless, none of these studies focus on hazard identification, instead they cover various topics ranging from the evaluation of accident reports (Kim et al. 2013) to the assessment of site safety management tools (Li et al. 2018). Thus, through a comprehensive synthesis of previous research, this review addresses the identification of highway construction safety hazards. Furthermore, although previous research has methodically identified construction hazards through site investigations (Abdul Hamid et al. 2003), this study considers the applicability of each hazard cited in the literature in order to comprehend the perspectives of the researchers and to create a comprehensive and exhaustive list of the hazards specifically in highway construction and maintenance projects.

Therefore, the objectives of this study were to develop a comprehensive list of transportation-related safety hazards, categorize the hazards, and rank them based on the frequency with which they are mentioned in the literature. The findings of this study will help employers in the transportation sector of the construction industry detect potential site safety hazards and take actions to lower the likelihood that highway workers will sustain occupational injuries.

METHODOLOGY

Online search engines like Google Scholar, ASCE Library, Science Direct, and Research Gate, as well as keywords like construction safety, occupational hazards in the construction industry, and construction hazards, were employed to compile a database of pertinent journal articles, theses, technical reports, and conference papers. The multistep exclusion process shown in Figure 1 was implemented to select the articles for in-depth review. Only articles published after 2000 were considered, to ensure that the results reflected researchers' current perceptions. Each of the 14 construction hazards identified were researched independently, and the physiological effects of each, as cited in the literature, were considered.

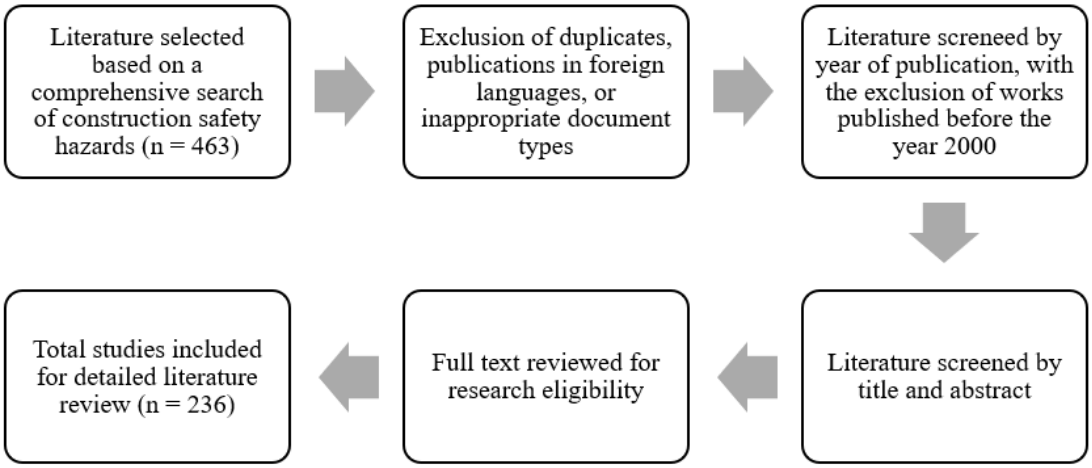

Figure 1. Multistep methodology for selection of relevant literature

RESULTS & DISCUSSIONS

Safeguarding construction employees from occupational injuries is of utmost importance, as the industry is well known for being labor-intensive (Safapour and Kermanshachi 2020; Nipa et al. 2021). This study categorizes and addresses the hazards that are most frequently encountered on highway projects and emphasizes the importance of identifying them so they can be minimized, controlled, or even eliminated. The 14 hazards identified were classified into four categories: (1) primary hazards, (2) physical hazards, (3) chemical hazards, and (4) ergonomic/other hazards. Primary hazards most often lead to fatalities, while physical hazards include different energy forms that could have a harmful impact on workers' health, either immediately or after sustained exposure. Chemical hazards, which include a wide range of gases, vapors, dusts, and fumes and encompass respiratory sensitizers, skin irritants, and carcinogens are similar to physical hazards in that their impact can be immediate or occur over or after a period of time. The final category includes ergonomic hazards, as well as the collapse of trenches. Table 1, which lists the hazards, categorizes them, and ranks them by frequency of citation in the literature, reveals that falls from heights is ranked as the number 1 hazard, followed by material and equipment handling, electrocution, heavy machinery, and struck-by incidents.

Table 1. List of hazards with frequency and rank

Type of Hazard	ID	Safety Hazard	Frequency	Rank

Primary Hazards	PR.1	Falls from heights	107	1
	PR.2	Electrocution	67	2
	PR.3	Struck-by incidents	62	3
	PR.4	Slips, trips, and falls at the ground level	60	4
	PR.5	Caught-in between incidents	47	5
Physical Hazards	PH.1	Noise	49	1
	PH.2	Extreme temperatures	39	2
	PH.3	Lighting and visibility	37	3
Chemical Hazards	CH.1	Hazardous materials	53	1
	CH.2	Airborne materials	32	2
Ergonomic and Other Hazards	EO.1	Material and equipment handling	76	1
	EO.2	Heavy machinery	68	2
	EO.3	Trench collapse	31	3
	EO.4	Vibration	28	4

Primary Hazards

The Bureau of Labor Statistics reports that falls from heights account for around 35% of all fatalities in the construction industry in the United States and are the primary cause of construction-related injuries in many other countries such as Singapore, New Zealand, Hong Kong, and Kuwait (Goh and Sa'adon 2015). Despite that, highway construction personnel have the third highest ratio of fatal fall accidents, following the commercial and residential sectors (Halabi et al. 2022). Nevertheless, the dangers of these accidents should not be disregarded. Wong et al. (2016) conducted an analysis of fatal construction falls from heights in Hong Kong and determined that they were primarily due to loss of balance, inadequate fall protection devices, platform malfunctions or collapse, and encounters with other objects, such as scaffolding. Falls from heights can be especially dangerous, as construction workers do not usually experience a free fall but instead encounter other objects that alter the mechanism of landing and cause bodily harm (Anantharaman 2022).

The majority of accidents on construction sites are fall-related and occur from heights or at the ground level (Anantharaman 2022). Slips, trips, and falls at the ground level are frequent incidences that commonly result in non-fatal musculoskeletal injuries (Gao et al. 2008). The loss of balance associated with slips and trips either leads to falls at the ground level or indirect injuries that result from the individual attempting to recover his or her footing (Antwi-Afari et al. 2018). The primary contributing factors to slips, trips, and falls are inadequate friction between the worker's footwear and the ground surface, poor lighting conditions, and inadequate housekeeping practices (Gao et al. 2008; Sanni-Anibire et al. 2020).

Electrocution, another primary safety hazard within the construction industry, occurs upon direct contact with an electricity source or indirect contact with a conductive medium. The risk of exposure to electrical currents is highest when construction workers are welding, working with live lines, or operating heavy machinery, including mobile cranes (Shiau et al. 2021); however, when effective safety precautions are in place, burns, damages to internal organs, heart attacks, and death can be prevented. Based on a study of fatal electrocutions in Taiwan's construction sector, the contributing factors were inappropriate use of personal protective equipment, lack of grounding, ineffective insulation, and failure to de-energize (Chi et al. 2012).

Construction activities are characterized by the constant movement of people and equipment that can result in struck-by injuries, which is the third most identified primary hazard and is caused by personnel colliding with falling objects or heavy equipment and machinery (Esmaeili and Hallowell 2012). On highway projects, safety measures such as lane closures and heavy barriers are required to prevent collisions between work crews and private vehicles (Hinze et al. 2005). Although there are many factors that increase the risk of struck-by fatalities, poor visibility has been found to be the leading cause, making adequate illumination a matter of life and death (Golovina 2016).

Caught-in-between accidents occur when an individual is caught or stuck between moving or stationary machinery or objects and are the second most common type of fatal accidents in construction. However, this safety hazard was determined to be the least cited primary hazard as demonstrated in Table 1. The heavy machinery and equipment increase the likelihood of caught-in between accidents, much like they do for struck-by incidents. Other factors contributing to this type of accident include poor visibility, failure to identify hazards, and inappropriate materials or equipment handling (Simutenda et al. 2021). To reduce occupational caught-in-between incidents, construction supervisors should emphasize the risks of working around heavy equipment, improve the frequency and quality of training, and ensure that workers are aware of where pinch, shear, wrap, and crush points are located (Chi and Lin 2018).

Physical Hazards

Construction noise was identified as the most frequently cited physical hazard. The main sources of noise on construction sites are machines that produce abrupt, erratic, high intensity, and difficult-to-control bursts of sound (Mir et al. 2023). While there is a greater focus on the impacts of noise on residents surrounding construction sites, construction personnel are the group most adversely affected. As well, they are the second most impacted group of noise-induced hearing loss, which has the ability to impair an individual's ability to conduct daily tasks (Cavallari et al. 2019; Okpala et al. 2022). Most construction equipment produces noise levels that range from 80 to 120 dBA overpower speech and auditory safety cues (Kwon et al. 2016), magnifying the risk of other hazards and increasing the number of occupational accidents (Okpala et al. 2022).

Construction projects often must proceed regardless of weather conditions (Safapour et al. 2017; Pamidimukkala and Kermanshachi 2021). Thus, workers are commonly exposed to extreme hot or cold temperatures that make them more susceptible to injuries from work-related hazards due to their physical or physiological reactions to their working environment (Vukadinovic and Radosavljevic 2020; Karthick et al. 2022a). Marinaccioa et al. (2019) found a positive correlation between occupational injuries and adverse weather exposure and highlighted the importance of employers having safety measures in place to protect workers from the impacts of extreme temperatures. The human body is sensitive to external temperature variations, and exposure to extreme temperatures disrupts the body's internal temperature, increasing its vulnerability to the

effects of heat or cold stress (Karthick et al. 2023). In addition to physical ailments, extreme temperature exposure can also result in reduced cognitive ability and increased accidents (Lee et al. 2019; Karthick et al. 2022b).

Although frequently disregarded, lighting conditions and other visual variables are crucial aspects of construction safety that significantly impact workers' safety, productivity, and comfort (Szer and Szer 2022). Adequate lighting in work areas improves workers' capacity to safely perform their tasks, while inadequate lighting reduces visibility and increases the likelihood of accidents occurring. Poor visibility is the cause of the majority of collisions with oncoming traffic or on-site equipment on highway projects, and it exacerbates the effects of other hazards, especially struck-by and heavy equipment-related accidents (Davila 2022). Adequate illumination is especially important for nighttime highway construction activities (Nnaji et al. 2020b).

Chemical Hazards

A variety of hazardous materials on construction sites that can cause occupational health risks are frequently disregarded. Skin contact, inhalation, and ingestion of emissions of substances like volatile organic compounds and semi-volatile organic compounds are notably dangerous (Gallon et al. 2020). Pesticides, biocides, formaldehydes, plasticizers, paints, and thinners are a few examples of volatile substances that may be present on jobsites (Kim and Yu 2014). Construction activities such as the production of hot-mix asphalt for roadway and pavement construction are associated with elevated emissions of volatile organic compounds, polycyclic aromatic hydrocarbons, and particulate matter (Boom et al. 2022), and inhaling these substances increases the probability of developing respiratory ailments. Similarly, continuous and prolonged inhalation of radon, a radioactive gas present in concrete, gypsum boards, and bricks, can manifest in respiratory disorders (El-Taher et al. 2010; Kim and Yu 2014). Construction workers are also at risk of exposure to biological hazards like mold and fungi, which thrive in damp environments. To lower the risk of exposure to hazardous materials, it is essential that these substances are clearly identified prior to the commencement of construction activities. Employers should strive to substitute hazardous materials when possible, but if that is not feasible, hazard awareness and the appropriate use of personal protective equipment should be emphasized and enforced.

The construction sector is responsible for approximately 75% of fine dust pollution and subjects workers to the risks of breathing contaminated air and developing related health issues (Cheriyan and Choi 2020). Construction dust is a by-product of many construction activities, including demolition, cut-and-fill operations, excavation, and concrete mixing. As particulate matter can easily penetrate the respiratory tract and lungs, inhaling it can have both immediate and long-term negative health effects (Azarmi and Kumar 2016). Inhalation of airborne particulate matter has been associated with a wide range of respiratory and cardiovascular diseases (Wang et al. 2022). To minimize the occupational hazards posed by these substances, appropriate control measures, such as the use of use of water suppression and local exhaust ventilation in conjunction with the use of personal protective equipment and sensor monitoring of particulate matter concentrations, should be put in place (Cheriyan and Choi 2020).

Ergonomic and Other Hazards

Operating heavy machinery carries with it an inherent risk for fatal or non-fatal injuries if the operator is not well trained or fails to follow the appropriate operating procedures. Tower cranes are an example of this type of heavy machinery commonly found on construction sites. They play an indispensable role in construction projects, but pose risks to workers, machinery, equipment,

nearby buildings, and people in the surrounding area (Zhou et al. 2018). These risks are associated with the multiple work phases involved in tower crane operations, where each phase presents a risk of an accident and needs to be controlled accordingly (Jiang et al. 2021). Human factors, environmental factors, management factors, and material factors affect the safety of tower crane operations, and a Hong Kong study found that among these categories, human factors have the greatest influence on safety outcomes, as most of the unsafe operations stem from ineffective safety training, poor communication, inadequate supervision, and the prioritization of time over safety (Liu et al. 2021).

Construction equipment and material handling are indispensable components of the construction process and refer to the manual or mechanical movements of materials. Employees who handle equipment and materials improperly run the risk of developing musculoskeletal disorders that can impair their day-to-day activities (Al Amin et al. 2013). Construction workers are more likely to suffer from musculoskeletal disorders or injuries due to ergonomic risk factors such as poor posture, excessive loads, repetitive motions, and overexertion (Kermanshachi et al. 2018; Pamidimukkala and Kermanshachi 2023). Construction equipment presents an additional risk, as each machine has a unique safety protocol and operating method (Pethaperumal and Sivakumar 2017). While unsafe practices are generally avoidable, they frequently result from human errors, including poor site safety management, inconsistent maintenance, and improper machine operation (Muralitharan and Elangovan 2014; Pamidimukkala et al. 2021).

Construction workers may experience constant vibrations of their hands, arms, or body when they are using hand-held or hand-guided tools such as breakers, grinders, and impact drills (Su et al. 2010). Occasional exposure to hand-transmitted vibrations is unlikely to have any adverse health effects, but prolonged exposure increases the likelihood of developing hand-arm vibration syndrome (Edwards et al. 2020), which affects neurological, vascular, and musculoskeletal systems and manifests as diminished hand sensations, decreased manual dexterity, and weaker grip strength. Construction personnel, specifically those who operate vehicles and equipment, can also be exposed to whole body vibration, which can negatively impact their lumbar spine, nervous system, gastrointestinal, and urogenital systems (Chi et al. 2017).

Excavation work entails the removal of soil or rock from the ground to create an open face. It is crucial to infrastructure development, but is inherently dangerous work and is associated with an alarming number of fatalities. The excavated earth at the trench's edge puts pressure on the trench walls that can cause trench collapses, cave-ins, water accumulation or flooding, a lack of oxygen, and exposure to hazardous substances (Akboğa Kale 2021). Trench collapse is the main contributor to both fatal and non-fatal excavation-related accidents (Jannadi 2008). Trench cave-ins are dangerous, yet their associated risks are often underestimated. They frequently occur in multiples, suffocating and crushing workers with collapsing soil that weighs more than one ton per cubic yard. Design, hydrogeological, and construction factors, including support reliability, timeliness, and installation specifications can aid in the prevention of trench-related accidents (Lin et al. 2021).

CONCLUSION

Unidentified hazards are unmanageable dangers; therefore, it is essential to identify all of the hazards on a construction site. Because construction projects are dynamic in nature, hazard recognition should start during the design phase and continue through all project phases to ensure that no hazard is missed. Within the construction industry, highway construction and maintenance are considered especially dangerous as evidenced by the high fatality and injury rates associated

with this sector. This study, which sought to identify the safety risks present on construction highway projects, resulted in the identification of 14 risks, which were then categorized into the following four groups: (1) primary risks, (2) physical risks, (3) chemical risks, and (4) ergonomic/other risks.

The risks were ranked within each category, based on how frequently they were mentioned in the examined literature, and the findings showed that falls from heights, material and equipment handling, heavy machinery, electrocution, and struck-by occurrences were ranked highest. Three of these risks, falls from heights, electrocution, and collisions, belong to the primary hazards group, which includes the hazards that most often result in fatalities. The rankings reflect the current perceptions of the researchers who authored the articles examined in the literature review. The results of this study will serve as a guide for employers who strive to protect their workers by identifying safety risks on highway construction job sites so that they can develop and implement effective safety management plans that lower the likelihood that their workers will be victims of occupational accidents. Since this paper strictly focused on the identification of highway construction hazards, future research could supplement this study to consider mitigation strategies for the management of these hazards, and how these strategies might differ amongst the different construction sectors. In an era of technological development, evaluating the role of advanced technologies in site safety management could also be beneficial in hazard identification and management. Such technologies include, but are not limited to, artificial intelligence, Internet of Things, and blockchain-based systems.

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