WORKtoZERO

an nsc program

Potential Technology Solutions to Address Hazards in the Crane Industry

nsc National Safety Council

NCCCO FOUNDATION

Contents

Executive Summary

The Work to Zero initiative at the National Safety Council (NSC) partnered with the NCCCO Foundation to develop data-driven content for individuals working in and around cranes to increase the awareness of risks and highlight technology solutions to reduce serious injuries and fatalities. For the first phase of the project, Work to Zero and the NCCCO Foundation surveyed more than 2,000 workers with active certifications in crane operations to identify the most common hazards in the industry and to understand the use and perceptions of different technologies that may eliminate or reduce occupational injuries. The purpose of this report is to expand on the survey findings and examine the current state of crane industry hazards and explore potential technology solutions to address those risks. This report includes an overview of 13 safety technology solutions that have the potential to eliminate or mitigate risks within the crane industry.

Introduction and Background

The NCCCO Foundation was founded in 2018 to promote safety in the crane industry through three pathways: education, research and workforce development. The National Safety Council (NSC) launched its Work to Zero initiative in 2019, supported by a grant from the McElhattan Foundation. The goal of Work to Zero initiative is to eliminate workplace fatality risk through technology by helping employers adopt safety technology solutions. The NCCCO Foundation and NSC partnered to explore employee perceptions of hazards within the crane industry, and potential safety technology solutions that could be used to address those hazards.

Work to Zero released its first white paper in 2020, *Safety Technology 2020: Mapping Technology Solutions for Reducing Serious Injuries and Fatalities in the Workplace*. NSC researchers reviewed data from the Census of Fatal Occupational Injuries (CFOI) and used Bureau of Labor Statistics (BLS) characteristic types (e.g., worker activity, event or exposure, primary or secondary source) to contextualize workplace fatalities within hazardous situations rather than looking at fatalities by industry or by event or exposure, in order to focus on situations that apply across industries (e.g., working at height) and identify overall workplace risks with the greatest potential for serious injuries and fatalities.

NSC categorized these workplace fatalities into one of 18 different hazardous situations, relevant across industries and worker activities (e.g., work at height, machinery operation, confined space entry) (Washburn, 2020). Through additional, supplemental interviews with health and safety professionals, NSC researchers also identified the inherent situational risks (e.g., fall, struck by) and the systemic contributing factors (e.g., lack of training, fatigue) that can exacerbate risk within those hazardous situations.

Work to Zero then created a survey to collect information from employers and employees across industries about which of these hazardous situations and risks were the most likely exposures and top contributors to injuries in their workplaces. A secondary objective of the survey was to collect data demonstrating the awareness, attitudes and usage of safety technologies within occupational settings. **In 2023, Work to Zero adapted this survey to incorporate language relevant to those working in the crane industry and invited individuals certified to work in and around cranes to participate in the survey. For more details on the survey, see the full report, *Understanding the Current State of Safety Hazards in the Crane Industry*.** This survey is referred to as the Work to Zero/NCCCO Foundation survey throughout this report.

This report expands on the survey report by examining hazards in the crane industry and injuries reported in the literature and national injury statistics. This report also provides an overview of 13 safety technology solutions with the potential to eliminate or mitigate risks within the crane industry. Eight technologies (i.e., camera systems and computer vision, drones, fatigue monitoring wearables, location geofencing, proximity sensors, robotics, virtual and augmented reality, and vital signs monitors) were included in the survey. Five additional technologies (i.e., anti-two block systems, ground penetrating radar, load moment indicator systems, load rotation and maneuvering devices, and anemometers) were identified in the literature or by subject matter experts. For each technology, insights from the survey respondents have been added to demonstrate usage and the benefits and drawbacks users experienced.

Hazards in the Crane Industry

Cranes play a vital role across various industries and occupations, improving operational efficiency and reducing the manual labor needed to lift, transport and place heavy materials on a jobsite. However, the complex interface between workers, machinery, management and the environment, combined with high task difficulty and the dynamic nature associated with industrial environments, all contribute to an increased risk of workplace incidents (Wu, Jin, Zheng, & Chen, 2024). According to the Occupational Safety and Health Administration (OSHA, 2008), common causes of crane incidents include:

- Electrocution
- Crane assembly and disassembly
- Boom buckling or collapse
- Crane overturns
- Rigging failure
- Overloading
- Struck by moving load
- Man-lift related accidents
- Working within the radius of counterweight
- Two-blocking[1]
- Hoist limitations

[1] When the load block or overhead ball collides with the boom tip

These crane-related incidents can amount to considerable personal and financial losses. Direct costs might include medical bills, workers' compensation costs, damage to equipment, or destruction of surrounding buildings or machinery. Indirect or intangible costs might include reputational damage, delayed work schedules or loss of productivity (Yu, 2017). According to the Konecranes Training Institute (2018), costs associated with crane-related injuries averaged over $200,000 per incident, while the average fatality amounts to over $4 million. Furthermore, across the 249 incidents reviewed in their study, there were 838 accompanying OSHA violations, contributing to $2.3 million in associated fines.

Injury Statistics

Across industries, CFOI data indicates there were 5,486 fatal occupational injuries in 2022, which is a 6% increase from 2021. The highest number of fatalities (1,620) occurred in the transportation and material moving industry. The next highest number of fatalities occurred in the construction industry (1,056), which was an 11% increase since 2021 (BLS, 2023). For comparison, 75% of the certified workers in the Work to Zero/NCCCO Foundation survey worked in the construction industry, and only 1% reported working in transportation, warehousing and material moving (Work to Zero and NCCCO Foundation, 2024).

Nationwide, fatalities due to vehicle/pedestrian interactions decreased 4% since 2021 and accounted for 325 fatalities. Fatalities due to extreme temperatures increased 19% over the past year though and accounted for 51 worker deaths. Eighty-four percent of those fatalities were due to extreme heat. Fatal injuries due to contact with objects and equipment also increased in the past year and accounted for 738 fatalities in 2022. Slips, trips and falls accounted for 865 fatalities in 2022, and 700 of those were falls to lower levels (BLS, 2023).

From 2011 to 2022, the CFOI reported 487 total crane-related deaths, an average of 41 per year over this 12-year period. Cranes were considered the primary source (i.e., the equipment responsible for the fatal injury) for 51% of the 487 fatalities, and the secondary source (i.e., the equipment that contributed to the fatal injury) for 49%. Of the fatal injury cases from 2011 to 2022, where demographics were recorded, men accounted for virtually all fatalities (99.5%). White, non-Hispanic workers accounted for 68% of fatal injuries, followed by Hispanic and Latino workers (14%), and Black or African American workers (3%) (BLS, 2024).

In the same period, 37% of fatal injuries involving cranes took place in the private construction industry. The manufacturing industry accounted for another 26% of crane-related fatalities, followed by trade, transportation and utilities (7%). Construction and extraction occupations (30%), transportation and material moving occupations (27%), installation, maintenance and repair (14%), and production occupations (10%) were among those occupations most impacted by crane-related fatalities (BLS, 2024).

At the time of the fatality, 42% of cases occurred while the worker was constructing, repairing or cleaning. A quarter of the incidents occurred when the worker was using or operating machinery and 14% occurred when the worker was performing vehicular and transportation operations. From 2011 to 2022, 40% of all fatal crane injuries (196 of 487) involved the worker being struck by an object or equipment. Fifty percent of those cases involved the worker being struck by a falling object or equipment, while an additional 12% involved the worker being struck by a non-transport vehicle. Falls to a lower level accounted for 8% of total cases, followed by transportation incidents (7%), and exposure to hazardous substances or environments (2.7%) (BLS, 2024).

In the Work to Zero/NCCCO Foundation survey, participants were asked to identify the hazardous situations and risks that contributed to or caused any workplace injuries (fatal and nonfatal) occurring on their jobsite(s) in the past two years (Table 1). These were injuries anyone on the jobsite may have experienced. In total, over 4,000 risks were identified. A worker being struck by an object or equipment accounted for 4% of risks. Falls from height accounted for 8% of the identified risks and being struck by a falling object accounted for an additional 7% of risks. The 335 participants who reported experiencing a personal injury (i.e., nonfatal injury) in the 2023 survey identified a combined total of 732 risks contributing to those injuries. For personal injuries, 9% of identified risks were falls from height, 8% were being struck by a falling object, and 2% were being struck by machinery or equipment (Work to Zero & NCCCO Foundation, 2024).

Table 1. Percent of hazardous situations and risks that caused or contributed to personal injuries or any injury on the jobsite in the past two years, as reported by survey respondents

Hazard	Personal	Site-wide
Heat stress or heat illness (including heat stroke)	18.3	15.8
Fatigue	17.8	9.8
Fall from height	8.7	7.7
Loading and unloading materials	7.5	8.3
Lack of proper training	6.7	7.7
Struck by falling object	5.6	7.1
Lack of workplace awareness (unfamiliar with site/surroundings)	5.1	5.3
Vehicle/pedestrian interactions	4.6	5.6
Hot work/welding	3.8	3.3
Lightning strikes	3.6	3.2
Struck by vehicle	2.3	3.0
Struck by machinery or equipment (including boom or jib)	2.2	4.0
Equipment overturn/tippage	2.2	3.3
Crushing during heavy equipment operation	2.0	2.0
Permit to work failure	1.9	1.2
Workplace violence (robbery, weapon or physical assault)	1.5	1.8
Confined space entry	1.4	1.9
Contact with overhead power lines	1.2	2.8
Entangled in machinery during repair and maintenance activities	1.0	1.0
Electrocution during construction and installation activities	0.8	1.1
Crane collapse	0.7	1.4
Trench collapse	0.7	1.3
Electrocution during repair and maintenance activities	0.4	1.2

In the 2023 Work to Zero/NCCCO Foundation survey, respondents were also asked what their most likely exposures were when working in the crane industry. Respondents reported they were likely or very likely to be exposed to heat (75%), falling objects (55%) and falls from height (50%). Regarding contact with equipment, 50% of respondents reported they were likely, or very likely, to be struck by machinery or equipment, and 53% indicated equipment overturns and tipping were likely exposures in the crane industry. Due to the high likelihood of exposure to the risks driving fatal injuries in the United States, hazards in the crane industry must be monitored and controlled in order to protect workers.

Technology in the Crane Industry

A number of technologies are available on the market today to eliminate or mitigate the hazards associated with crane operations. However, there is a lack of research on the role of technology for improving crane safety (Zhang & Chen, 2023). Therefore, this section is intended to compile and review the available technologies and their associated use cases for safety in crane operations. It is noteworthy to mention that some of these technologies are still considered to be early in their development, and/or may not be widely used within workforces (Lingard et al., 2019). Furthermore, successful use of technology may require one or more solutions to ensure a holistic approach to workplace safety.

Anti-Two Block Systems

Anti-two blocking (ATB) systems are an integral safety mechanism integrated into most modern cranes. Two-blocking occurs when the load block or overhead ball collides with the boom tip, potentially causing the hoist line to break and the attached load to fall. These incidents can damage the crane itself and carry the risk of causing severe injury or death to the operator and nearby workers (Heavy Equipment Colleges of America, 2024). ATB systems consist of switches or sensors mounted on the boom tip, and an accompanying weight attached to a chain or cable. When the load block is hoisted, the switches are activated. If the load block gets too close to the boom tip, the system will alarm to warn the operator of the potential collision and automatically disable the hoist mechanism from pulling the hook any closer (Heavy Equipment Colleges of America, 2024). OSHA requires ATB systems be equipped for the following crane types:

- Telescopic boom cranes manufactured after 1992
- Articulating cranes equipped with a load hoist manufactured after 1999
- Lattice boom cranes and derricks manufactured after 2011 (OSHA, 2010a)

Camera Systems and Computer Vision

Cameras are a widely utilized technology for monitoring and collecting visual data during crane operations (Zhang & Chen, 2023). Cameras can be mounted on various parts of the crane, such as the boom or jib, to provide site managers, lift directors and operators with a clear view of the hoisted load and the surrounding area. One limitation of these systems is that they require a human operator to continuously monitor photo or video streams. However, computer vision and video analytics are increasingly being integrated into these camera systems to draw inferences and make predictions leveraging artificial intelligence or machine learning algorithms.

SURVEY INSIGHT:
11% of survey respondents (n=1,065) reported currently using or having previously used camera analytics in the crane industry. Users described the benefits of cameras including the elimination of blind spots and increased site security.

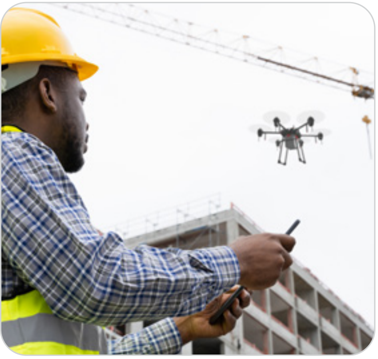
For crane operations, cameras can be used to monitor the hoisted object itself (Chen, Fang, & Cho, 2017; Chen & Lou, 2019; Zhou et al., 2019), with more advanced systems able to assess the clearance between objects and warn the operator of potential collisions (Chen et al., 2017). Computer vision algorithms have also been shown to provide a reliable and accurate solution for identifying crane load fall zones and determining workers' positions relevant to them (Pazari, Didehvar, & Alvanchi, 2023). Cameras can also be used to monitor worker locations (Price et al., 2021; Yang et al., 2019), along with other dynamic variables on the ground level (Yang et al., 2019). In particular, a broad view of personnel placement and site specifics may benefit lift directors when carrying out their responsibilities in relation to preparing for and overseeing lift operations. Camera systems are a popular safety technology due to their cost-effectiveness and the ability to gather high-resolution data (Price et al., 2019). However, finding the ideal place to mount the cameras remains a challenging task, as obstructions such as buildings, machinery or materials can obscure the camera's vision (Zhang & Chen, 2023). Other variables, such as lighting and environmental conditions (e.g., rain, fog, dust) may also impact the ability to capture and analyze images.

Case Study Highlight

Camera Solution for Operating in the Blind

In certain situations, crane operators may struggle to see a load or its placement due to limited visibility, distance or other obstructions. While spotters and signal persons play a vital role in relaying instructions, the ability to safely control the load or react to changing circumstances may be delayed, increasing the risk of serious incidents and fatalities (SIFs). These risks include workers or pedestrians being struck-by or caught-between incidents, pinch point injuries, crane collapse or tipping, falling materials, or damage to nearby structures or equipment. To address these risks and enhance site safety, Garney Construction began piloting HoistCam™ a high-definition, rugged wireless camera that attaches to the block of a crane (or other metal components) via high-strength magnets. The cameras allow operators to view real-time video footage of the worksite, providing them with direct visibility of the load, the surrounding area and potential blind spots.

During the pilot, Garney relied primarily on operator feedback and performance as the initial measure of success. Through increased visibility of the surrounding area and the load, the operator reported greater awareness of the surrounding area, allowing for a safer and better-informed lifting process. This also helped reduce the mental load needed to safely hoist and place materials, contributing to increased confidence and less stress for the operator. The system also had tangible benefits on site productivity, increasing the speed and accuracy of material placement. At the time of the case study, Garney's internal field technology team has recommended the technology for immediate implementation on projects where cranes are operating in the blind. They also identified additional use cases for the technology, such as excavator operations, to reduce risk in other areas of the worksite.



Drones

Drones are unmanned aerial vehicles (UAVs) designed to carry a payload, including information collection technology. Built-in navigation and control systems enable remote, semi-autonomous, or autonomous flight within and beyond the operator's line of sight (Winter & Metcalfe, 2020). Camera-equipped drones can be used to mitigate the risks associated with crane operations, particularly during "blind lifts" when the crane and its payload are not fully visible (Roberts, Bretl, & Golparvar-Fard, 2017).

For instance, during site inspections and lift planning, drones can be leveraged to capture high-definition photos and live videos of the worksite at various angles and elevations.This approach minimizes worker exposure to hazards, such as work at height, without relying on potentially outdated aerial views via Google Maps or other related services. The use of UAVs can contribute significantly to crane safety by allowing construction managers, lift directors and crane operators to gain a comprehensive view of the crane's surroundings. Thus, drones can be used to provide lift directors with a better view of the entire project including personnel placement to help them understand where workers are in relation to others and equipment. Furthermore, by providing real-time feedback on the crane's position and its immediate environment, UAVs have been shown to be a promising method of identifying potential hazards and preventing accidents (Roberts, Bretl, & Golparvar-Fard, 2017).

SURVEY INSIGHT:
13% of respondents (n=1,212) reported currently using or having previously used drones related to crane operations. Many users described operating drones for crane inspections and viewing jobsites to help identify the best location to operate the crane.

Case Study Highlight

Addressing Safety and Operational Efficiency with Drones

During site inspections and lift planning, workers often need to perform inspections at height, exposing them to risks of falls, equipment failure and other height-related hazards. Damaged or deteriorated structures can further exacerbate these risks. Additionally, the surrounding environment also needs to be inspected to ensure the terrain is level and stable enough for safe crane operation. Surface expressions, referring to the flow of crude oil, water and/or steam to the Earth's surface, are one such high-risk phenomenon. Workers who perform these inspections face hazards such as high temperatures, unpredictable releases of gas or liquids, and compromised ground stability. In 2009, in response to a job requiring an inspection at height, Huddleston Crane Service began investing in drones to mitigate the risks faced by its workers and to facilitate both lift planning and emergency response planning.

The use of drones has had significant benefits on both safety and operational efficiency within the organization. In response to the hazards associated with inspections at height and proximity to surface expressions, drones are used to capture high-definition photos and live videos of the worksite at various angles and elevations. This approach minimizes worker exposure to hazards while also improving the quality of site inspection and planning. Instead of relying on potentially outdated aerial views via Google Maps, drones offer more realistic and detailed visuals, enabling lift directors and operators to precisely plan crane movements, create lift plans, identify power sources, and visualize nearby streets or buildings. These images are also used to facilitate emergency response planning, including the identification of emergency shut-offs, evacuation routes and muster locations. Huddleston Crane Service has been utilizing drone technology for nearly 15 years. Since beginning as a small-scale project, it has upgraded the technology an estimated seven times, adding additional capabilities including zoom inspections, thermal inspections, wide-angle visibility, GPS metadata and collision detection.

Fatigue Monitoring Wearables

According to the NSC/NCCCO Foundation survey, fatigue was identified as the second most common systematic risk contributing to crane-related injuries (Table 1). Fatigue can result in a lack of alertness, slower reactions to signals or situations, and impact a worker's decision-making processes. Construction workers in particular are at a high risk for fatigue, due to prolonged working hours, physically and mentally demanding work, and working in the elements (Lingard et al., 2019). To mitigate these risks, fatigue monitoring wearables can be deployed as a means of identifying and alerting to potential fatigue, providing timely support for crane operators, site supervisors and safety personnel (Li, Chi, Zhang, & Shen, 2019).

Fatigue monitoring wearables use a range of sensor technology or visual cues to accurately assess a worker's fatigue and impairment levels. Three common types of monitoring capabilities include electroencephalography (EEG) sensors to monitor brain activity relative to fatigue, monitoring for visual cues and microsleeps, and using sleep and activity data to calculate fatigue risk levels (Work to Zero, 2021a). For workers, a series of visual, audible or haptic alerts can be delivered to notify them they are showing signs of fatigue or impairment, prompting them to take necessary precautions or breaks. Employers can also use these data to make informed and proactive decisions regarding worker fatigue. For example, a study on wrist, hip and ankle fatigue monitoring sensors demonstrated that meaningful fatigue-related safety data can be collected by an employer in a cost-effective manner without interfering with a worker's daily routine (Cavuoto & Megahed, 2018).

Ground Penetrating Radar

OSHA (2010b) requires that cranes are assembled on ground that is firm, drained and graded to a sufficient extent to meet the equipment manufacturer's specifications for adequate support and degree of level of the equipment. Ground-penetrating radar (GPR) is a noninvasive technique that generates images of the subsurface by using electromagnetic energy reflections. It offers a continuous, real-time view of soil and geological features beneath the surface, allowing for the identification of various subsurface interfaces and objects without the need for excavation (USDA, 2021). GPR can be used for a variety of construction-related applications, including assessing roads and pavements, detecting underground utilities (e.g., pipes, tunnels and sewers) and for scanning buildings or other structural components (Elshaboury et al., 2023).

Use of GPR has been proposed for various applications during crane and lift planning. Modern GPR equipment often feature user-friendly interfaces, allowing workers to quickly and efficiently perform basic assessments before and during projects (Caldwell, 2023). For crane operations, GPR has been used successfully to assess ground (Maverick Inspection, 2014) and pavement stability (Ciampoli et al., 2017) to ensure safe crane placement. Its use has also been proposed as a means to identify areas for crane anchors or to identify utility lines in the area (Caldwell, 2023).

Load Moment Indicator (LMI) Systems

One of the most important considerations during crane operations is ensuring the load being lifted remains within the crane's rated capacity; failure to do so can result in crane tipping or collapse (OSHA, 2014). Load indicator systems are designed to assist operators and riggers by continuously monitoring the load weight and other key indicators, such as boom length, angle and radius. If the crane exceeds any of the programmed thresholds, these systems can alert operators via visual or audible notifications and disable operations. (Kalairassan, Boopathi, & Mohan, 2017). Use of LMI systems allows operators to take corrective action to ensure the load does not overload the machine, mitigating potential incidents.

Load Rotation and Maneuvering Devices

Load rotation and maneuvering devices assist the lifting crew while lifting, maneuvering and setting materials to minimize the risk of load swing (Lingard et al., 2019). Some devices, such as the Verton R-Series, dynamically rotate and position crane loads, while others, such as the Buildvation "Rigger Assist," work by providing real-time data insights to assist crane operators and riggers. The Verton R-Series is a remote-controlled under-hook load rotation system, which leverages a remote-controlled gyrocopter to rotate the load suspended under the crane hook (Smith, 2018). The Rigger Assist technology is a retrofit product that can improve the accuracy and effectiveness of the riggers by actively monitoring and displaying data and recommendations from sensors placed on the crane, as well as parameters from the crane computer (Smith, 2018).

Location Geofencing

Location geofencing leverages location-based data sources, such as the Global Positioning System (GPS), Radio Frequency Identification (RFID), LiDAR (Light Detection and Ranging), Wi-Fi or cellular data to create "virtual barriers" around a geographic area. When a location-enabled device, such as a mobile phone, wearable sensor or in-cab GPS, crosses the geofenced boundary, a series of predetermined actions or responses will trigger. Location geofencing is typically a feature integrated within other commercially available safety technologies, such as proximity sensors, wearables, mobile applications, or vehicle or equipment monitoring systems (Work to Zero, 2024). Location geofencing has been utilized in a variety of industries (e.g., construction, manufacturing, forestry) to mitigate the risk for collisions, caught -in or -between incidents, or contact with equipment.

By defining boundaries for different zones, such as loading, unloading and transportation zones, geofencing can serve as a potential countermeasure to reduce risk (Javed et al., 2020). For example, it can be used to delineate pedestrian zones, restrict access to hazardous areas, and even de-energize or deactivate nearby machines or vehicles (Blanchard, 2020). When combined with other technologies, such as wearables and proximity sensors, workers can not only be alerted when they enter or exit a geofenced area, but also when they are within an unsafe distance of moving equipment (Idris & Pennington, 2023). For crane operations, location geofencing might be leveraged as a means of detection and notifying operators, workers and site supervisors if a person or object is within an unsafe proximity to the crane, or if the crane enters a hazardous area of the worksite.

SURVEY INSIGHT: 12% of respondents (n=1,069) reported currently using or having previously used location geofencing for workplace safety. Users described its benefits to include keeping unauthorized people out of dangerous areas and notifying workers of specific zone risks. Some described drawbacks included over-reliance on the technology.

Proximity Sensors

"Struck-by" and "caught-between" injuries are both part of the OSHA "Focus Four Hazards," which are priority topics for construction safety training (OSHA, 2023). Sensors for proximity monitoring are devices that detect objects nearby, or within a set radius, without physical contact up to a nominal range or sensor vicinity. When an object – either person or equipment – enters the sensor's determined range, the associated detection method will record the activity and send data back to the sensor, warning devices or platforms. Common technologies used for vehicle proximity sensing include infrared, radio frequencies, Bluetooth and specialized lasers. (Work to Zero, 2021).

For crane operations, safety monitoring of proximity to a crane, and its load, is a critical safety task in reducing injuries and fatalities at jobsites. Use of these sensors can promote safety by providing real-time alerts for workers on-foot and equipment operators when potentially hazardous proximity situations exist (Marks & Teizer, 2012). Commercial crane proximity safety management systems tend to focus on monitoring the crane components flying over sensitive zones (e.g., railway lines, power lines, highways, public areas, school yards, buildings, bridges and roads) and preventing collisions (Luo, Leite, & O'Brien, 2014). Proximity sensing technologies for preventing vehicle strikes are usually deployed onto equipment and vehicles with simple sensing technology hardware and associated tags or devices worn by workers. These deployment options allow the technology to fit into existing worksite layouts, reducing operational downtime to a minimum (Work to Zero, 2021b).

SURVEY INSIGHT: 28% of respondents (n=1,223) reported currently using or having previously used proximity sensors in the crane industry. One respondent described, "It notifies you if your counterweight is on a collision course when setting up your swing radius." Overreliance, and even complacency, were noted as potential drawbacks to using this technology.

Robotics

The use of robotics in crane operations has the potential to increase efficiency, accuracy and safety on the worksite. Autonomous robot cranes (ARC), for instance, are integrated with artificial intelligence capabilities and can perform tasks autonomously or be remotely controlled by a human operator. These technologies often come equipped with object detection capabilities, enabling them to identify nearby workers or objects and avoid potential collisions (Global Infrastructure Hub, 2020).

Although robotics has shown promise for applications in freight and logistics (Global Infrastructure Hub, 2020), there are barriers associated with their widespread adoption. First and foremost, more research is needed to better understand the use and potential safety implications associated with autonomous crane control (Zhang & Chen. 2023), including those across various industries and under different conditions. Compared to traditional cranes, ARCs are associated with higher-up front resources and financial investments. To build the business case for these technologies, return-on-investment assessments should account for the potential savings associated with reduced safety incidents and human error. Furthermore, ARCs require a reliable energy network to power the machinery, along with a reliable GPS, WiFi or cellular network (Global Infrastructure Hub, 2020). This may not be possible in certain industries located in remote or isolated areas, such as mining, agriculture or forestry.

SURVEY INSIGHT: 8% of respondents (n=1,210) reported currently using or having previously used robotics for workplace safety. Most users described having used them for confined space entry on jobsites.

Virtual and Augmented Reality

Virtual reality training is designed to immerse the user into an entirely computer-generated environment, while still allowing the individual to navigate the environment as if they were physically there (Work to Zero, 2020). This approach offers a more hands-on and personalized experience for learners (Brown & Pennington, 2022). VR has been used to simulate crane operations in a realistic and immersive environment, allowing participants to react to dangerous situations in a controlled environment, practice tasks until they master the required skills and prepare operators for challenging working conditions (Juang, Hung, & Kang, 2013).

For instance, Song et al. (2021) introduced a set of VR training systems to teach participants to safely operate three crane types (overhead, container and tower crane). The findings indicated students reported higher self-efficacy after using the VR training simulator, indicating an increased competence in crane controlling skills. Other VR systems can be used to enhance engineering lift planning, increase workplace awareness, and evaluate and mitigate lift-related risks (Pooladvand et al., 2021). The technology has shown promise in that it has the potential to reduce the risk of accidents caused by untrained or unskilled operators (Song et al., 2021) and reduce the potential costs associated with training (Juang, Hung, & Kang, 2013).

Augmented reality (AR) is a technology that creates interactive content by overlaying digital information, such as messages, videos, images or directions, onto the real world. Typically, AR content is deployed on head-mounted displays (e.g., helmets, goggles or glasses) or via mobile devices (Idris & Pennington, 2023). While still early in its maturity, AR has shown some promise for crane safety applications. Research by Chen et al. (2016) and Chi et al. (2012) developed computer interfaces to improve the user experience for teleoperated cranes. Using AR, these systems can display key information, including real-time site images, information about the lifted object, crane loading and movement data, and environmental data. The findings from these studies indicate AR can significantly assist in the operation of remote cranes and reduce the mental load placed on the operator (Zhang & Chen, 2023).

SURVEY INSIGHT: 14% of respondents (n=1140) reported currently using or having previously used virtual or augmented reality. Most reported using it for training purposes. One respondent said, “This helps inexperienced trainees to understand boom deflection effects, and how to control loads and charts, before learning the hard way.” Others described the benefits of training without the risk of injury or property damage. Most emphasized how it should be used in addition to, not in place of, traditional training.

Vital Signs Monitoring Wearables

Heat stress was identified as the number one risk factor contributing to injuries reported by survey respondents (Table 1). In general, heat stress can contribute to an array of serious illnesses and injuries, including heat cramps, heat exhaustion or heat stroke (Leiva & Church, 2022). Complex cognitive tasks can also be impacted by heat stress and dehydration (Piil et al., 2018), which can be particularly concerning for workers performing skilled and potentially dangerous work (Morrissey et al., 2021). In 2022, OSHA identified over 70 industries likely to experience heat-related hazards, including construction, manufacturing, maritime and mining (OSHA, 2022).

Vital signs monitoring wearables are sensor-equipped devices that monitor the physiological metrics of the individual wearable wearing them (Idris & Pennington, 2023). In the context of heat stress, wearables provide a noninvasive and portable means of monitoring the body's physiological responses to heat (Notley, Flouris, & Kenny. 2018), such as core body temperature, blood pressure, heart rate or fluid loss (NIOSH, 2016). For workers, these devices can provide automatic data visualization or interpretation, warning signals or even direct instructions to rest in response to heat strain (Pizzani, Cauda, Morrissey, & Mills, 2023). For employers, these data can be leveraged to better understand which occupations, locations or tasks face an increased risk of heat-related illnesses or injuries and inform work practices and controls (Callihan et al., 2023).

SURVEY INSIGHT: 14% of respondents (n=1,194) reported currently using or having previously used wearables to track health risks or vital signs monitors. Open-ended responses describing these devices included comments about how benefits included receiving real-time feedback on health and identifying workers who may not be fit for duty so they can be removed from dangerous tasks. Concerns over data privacy were also included in the responses.

Wind Speed Indicators (Anemometers)

Wind is a significant threat during crane operations, potentially impacting crane stability, load movement and control. According to the American National Standards Institute, winds contributed to 23% of tower crane incidents reported worldwide between 2000-2010 (Kelechava, 2016). OSHA (2014) requires that crane operations are paused if conditions exceed the speed recommended by the manufacturer or a qualified individual. Wind speed indicators, or anemometers, help mitigate these risks by continuously monitoring wind speed and direction. Often, these devices are equipped with audible and visual alarms, which will notify personnel when wind speeds have exceeded the programmed threshold (Lingard et al., 2019).

Future Directions

The National Safety Council is committed to continuing to work to understand best practices for adopting technology in order to save lives. Partnering with the NCCCO Foundation provides an opportunity to explore specific hazards and the effectiveness of safety technology within the crane industry.

Technology solutions are available that may help eliminate or mitigate risks in the crane industry leading to injuries. Technology may also increase operational efficiency and maximize ROI for companies implementing these solutions. Currently, there is limited use of these technologies in the crane industry. According to the survey, depending on the type of technology, only 2% to 22% of respondents reported they were currently using these solutions at their jobsites. Additionally, only 15% of respondents reported they were very familiar with these technologies, while 55% reported moderate to slight knowledge, with the remaining 30% reporting no knowledge at all.

Despite low use and familiarity with a range of technology solutions, responses indicated a high general acceptance of and willingness to try new technologies. Seventy-eight percent of respondents agreed they were open to trying new technology in the workplace, and if they worked, they would continue to use them (Work to Zero and NCCCO Foundation, 2024). Similarly, only 15% of respondents said they did not trust new technologies.

Openness to using new safety solutions is a critical first step in implementing technology in any workplace. Employers considering adopting technology need to engage their workforce and all stakeholders early on in the process to gather feedback on how it can be best used and what barriers may be in place for innovation. For more information on digital readiness and understanding how to prepare for technology adoption, see the Work to Zero paper, *Determining Readiness for Safety Innovation and Industry 4.0* (Lin, Guasta, & Whitcomb, 2021).

The crane industry may have unique challenges for technology implementation. The survey was adapted to ask questions about "jobsite(s)" instead of "workplace" to address the fact that many certified workers in the crane industry work at multiple jobsites over the year and may also be working with different employers and in different states. Depending on the specific job, the employers' resources, and the state's regulations may determine what technology can be used and what site-specific training may be necessary.

Sharing experiences with technology through case studies may be beneficial in driving innovation in the crane industry. Thirty-nine percent of survey respondents reported being more comfortable with technologies that had been around for longer periods of time. New and potential users are interested in understanding the process, impacts and lessons learned from early adopters. Sharing these experiences can provide opportunities to learn about the specific considerations for using technology in the crane industry and can contribute to identifying best practices for others interested in innovation.

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