Work Zone Intrusion

Technology to Reduce Injuries & Fatalities

By Chukwuma Nnaji, John Gambatese and Hyun Woo Lee

Consider the following descriptions of three incidents in which work zone intrusions resulted in injuries and fatalities of construction and transportation workers.

IN BRIEF
- Work zone incident statistics indicate that there is room for improvement in safety for both workers and motorists.
- Safety technologies such as work-zone intrusion alert technologies are not widely used in highway work zones. Most highway construction stakeholders are not aware of the potential for incident reduction that such technologies can offer.
- Implementing work zone intrusion alert technologies in a highway construction work zone could help improve the safety of roadway construction and maintenance workers.
- Current work zone intrusion alert technologies should be improved to increase their adaptability.

Case 1: On March 13, 2017, two construction workers were killed in a work zone by a hit-and-run driver. A third was severely injured. The workers were conducting a ditch inspection when a car veered off the lane and crashed into the work zone (Johnson, 2017).

Case 2: On April 7, 2017, at approximately 3:00 a.m., a vehicle drove into a cut-off emergency lane and struck four DOT employees who were sanding and painting metal structures beneath an overpass. One worker was declared dead at the scene of the crash while two workers were severely injured (Park & Clark, 2017).

Case 3: Following some erratic driving upstream, a vehicle entered into a highway work zone and hit a company vehicle parked in the work zone, then ran over several barrels before coming to rest. Prior to crashing into the stationary company vehicle, a worker was hit and killed (Reese, 2016).

A consistent undertone in the three cases is the cause of the fatality: a motorist intruding into a predetermined and closed-off work zone. To keep the roadway open to the public during construction, highway construction workers are often exposed to the hazards of working in close proximity to live traffic. According to CDC (2016), 1,435 workers died on duty between 2003 and 2014, averaging about 115 fatalities per year. Vehicles intruding into a work zone are considered a primary source of worker fatalities. In addition, CDC (2016) reports that approximately 50% of fatalities recorded between 2011 and 2014 were attributed to vehicles hitting a worker in a work zone. The results from a survey conducted by Associated General Contractors of America (AGC, 2015) indicate that approximately 50% of all U.S. roadway contractors witnessed a work zone intrusion in 2014.

Positive protection systems such as mobile barrier trailers and truck-mounted attenuators (TMA) can be implemented in work zones to protect

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workers from impact of intruding vehicles (Hallowell, Protzman & Molenaar, 2010; Tymvios & Gambatese, 2014). Although widely considered effective, the high initial cost of using positive protection measures creates an obstacle for extended diffusion of the devices (Brillhart, 2010; Schrock, Fitzsimmons, Lindheimer, et al., 2014).

Conversely, a work zone intrusion alert technology (WZIAT) offers an alert-producing mechanism with the potential of securing needed reaction time for workers in the event of a vehicle intrusion into the work zone. WZIAT was first introduced to work zones in 1995 following a Strategic Highway Research Program (SHRP)-sponsored study (Agent & Hibbs, 1996). Since the SHRP program, several WZIATs have been developed, evaluated by departments of transportation (DOTs) and implemented in work zones on many highway projects. Despite its introduction more than 20 years ago, WZIAT has not been widely used in work zones (Wang, Schrock, Bai, et al., 2011). This phenomenon could be attributed to several factors such as reported inaccurate alarms, difficulty to install and retrieve devices, and low product awareness (Wang, et al., 2011).

As noted, a primary reason for poor diffusion of WZIATs is a lack of information on their usefulness and effectiveness. Given the potential of these technologies, the authors conducted a study targeted at determining the level of WZIAT awareness among highway construction stakeholders. The study also aimed to provide a summary of commercially available WZIATs, considering that there is a dearth of studies summarizing basic performance information of these devices. Finally, the researchers investigated the potential usefulness of WZIATs on reported fatal work zone intrusion cases.

Methods

To determine the level of WZIAT awareness in the highway construction industry, the authors developed and administered a survey using the Qualtrics online survey tool (OSU, 2018). The survey was designed to elicit from stakeholders observed benefits and obstacles to implementing WZIATs. To conduct the survey, the authors prepared a questionnaire that consisted of three main sections.

The first section solicited demographic information from participants to provide data on the characteristics of each respondent (e.g., position/title, years of experience). The second section requested participants' general knowledge of work zone safety technologies. The third section asked participants questions specific to work zone intrusions and WZIATs.

The target audience for the survey included contractors, subcontractors and DOTs in the U.S. and Canada. In addition, the authors conducted an in-depth literature review and website search to generate applicable content on WZIATs for highway construction stakeholders. Finally, the researchers identified and evaluated work zone fatality cases captured in the NIOSH Fatality Assessment and Control Evaluation (FACE) program to determine whether WZIATs could have prevented the reported fatalities.

Survey Results

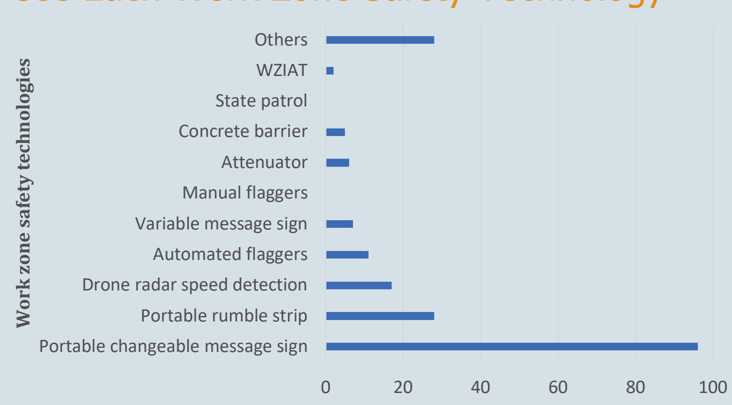
The researchers sent e-mails directly to 296 contacts consisting primarily of American Association of State Highway and Transportation Officials (AASHTO) members and members of the AGC Oregon-Columbia Chapter to request their participation in the survey. The AGC Oregon-Columbia Chapter was purposively targeted to ensure that adequate input from industry experts would be captured. A purposive sampling was performed given the specificity of the information required from respondents and to limit the potential of a low response rate.

The request-to-participate e-mail asked recipients to also forward the message to other professionals involved in highway construction. However, not all 296 e-mails reached the intended target population due to some unresponsive e-mail addresses. A total of 114 responses was received. Of those, 111 (97%) were substantially complete. A total of 102 respondents (89%) fully completed the survey. Approximately 65% of responses received were from individuals affiliated with a government agency, while 32% originated from general contractors. Responses received were primarily from project managers (51 responses from DOTs and general contractors), while project engineers, traffic control designers and safety officers made up 36% of responses. Members

TABLE 1
Responses by State & Province

No. of responses	States/provinces
1	AL, CA, CN, DC, DE, FL, HI, IN, KS, MI, MT, NH, NV, OK, PA, SC, SD, UT, VA, VT, WA, WV and SK (Canada)
2	AK, IA, MN, MS, NJ and WY
6	OH
24	OR
32	BC (Canada)

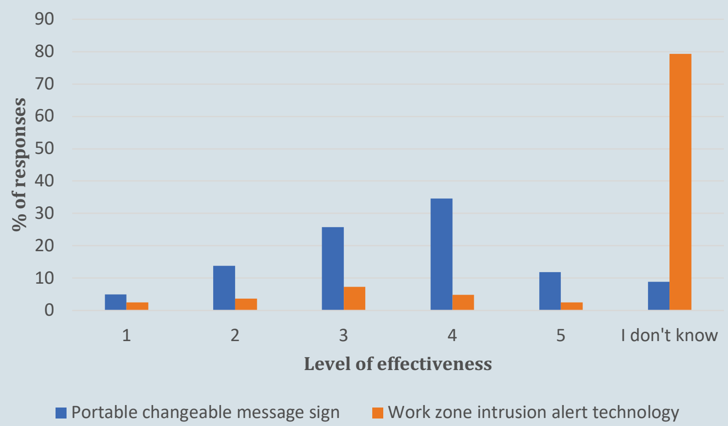
FIGURE 1
Respondents Currently Using or Planning to Use Each Work Zone Safety Technology



Note. n = 102. *Multiple responses allowed.*

FIGURE 2

PCMS & WZIAT Incident Prevention Effectiveness



***Note.** 1 = minimally effective; 5 = highly effective.*

TABLE 2

Alert Types for Each Technology

Technology	Alert type: Audio	Haptic	Visual
Intellicone	x		x
Intellistrobe	x		
SonoBlaster	x		
Traffic Guard WAS	x	x	x

of 32 U.S. states and two provinces in Canada participated in the survey (Table 1, p. 37).

Oregon provided 24 responses, largely due to the participation of AGC Oregon-Columbia Chapter members. Of the 33 responses received from Canada, 32 were from British Columbia and one from Saskatchewan. The relatively high number of participants from British Columbia could be a result of a significant interest in work zone safety in British Columbia.

The survey asked participants about the types of work zone traffic control devices used on their projects. The results (Figure 1, p. 37) indicate that portable changeable message signs (PCMS) are widely used on highway projects (94%), while WZIATs are the least-used technologies (2%).

Similarly, PCMS was selected as the most effective technology and WZIATs as the least effective (Figure 2). Furthermore, few respondents consider portable rumble strip (9%), drone radar speed detection (5%) and automated flagger (3%) as highly effective work zone technologies. Note that approximately 80% of the respondents indicated not knowing the effectiveness of WZIATs. This finding supports, in part, existing literature that suggests work zone intrusion alert systems are not currently widely used in the construction industry (Wang, et al., 2011). To validate this finding, the researchers asked survey participants whether they had used or are using WZIATs on any project. The responses show that only 10% of participants had prior knowledge of and intention to use WZIATs. It could be inferred from this result that highway stakeholders have neither adequate exposure to nor adequate information on WZIATs.

Respondents were also asked what type of work zone intrusion occurred frequently in their experience. Consistent with past studies (Bryden, Andrew & Fortuniewicz, 2000), 65% of respondents indicated that full intrusions (i.e., vehicle intrusion into the work zone through the taper) were the most prevalent type of intrusion followed by buffer intrusions (51%) (i.e., contact with vehicle outside the work zone, such as sideswipe contact incidents). Approximately 15% of respondents indicated not witnessing any intrusions.

Noteworthy statements from participants indicating the respondents' perceptions of WZIATs include:

- "Never used one or even heard of them in our province. Definitely want to know more."
- "I believe that any attempt to alert workers of intrusion is beneficial to work zone safety."

Although more than 100 responses were received and analyzed from 32 states, generalization of the findings should be made with caution since approximately 50% of the data were collected from Oregon and British Columbia.

Current Work Zone Intrusion Alert Technologies

Four intrusion alert technologies are currently commercially available (see sidebar on p. 41 for a list of technologies studied and demo videos for each). Following is a brief description of each technology, its capabilities and how it can be applied in work zones. Table 2 summarizes the types of alerts produced by each WZIAT.

Intellicone

Intellicone (Highway Resource Solutions Ltd.) is a wireless audio-visual alarm system that provides audible tones of different pitches and oscillating visual cues over a long distance. Consequently, construction and maintenance workers are provided additional reaction time if an intrusion occurs before the activity zone. Although configuration varies according to type, the device primarily comprises a portable site alarm and strobe lamps. The strobe lamps are each fitted on a cone, which activates the devices and allows them to communicate with each other, thus creating a wireless network using a relay system. Each strobe lamp has a transmission distance of approximately 65 ft (20 m). The alarm is a battery-powered unit that produces a visual and audible warning alert when a vehicle breaches the device's network (Highway Resource Solutions, 2016a, 2016b).

Intellistrobe

Intellistrobe (Intellistrobe Safety Systems) is an automatic safety alarm system used in work zones primarily as an automated flagger assistance device. The system is equipped with a gate arm, signal lights, pneumatic hose and audio alerts. Using a transmitter, an operator controls the unit electronically from a safe distance (Intellistrobe, 2018). In addition to its primary function, the system is used as an intrusion alert technology. The audio alert is triggered when an errant vehicle pressurizes the hose. The researchers found no studies that evaluated the system's effectiveness as an intrusion alert technology.

SonoBlaster

SonoBlaster (Transpo Industries Inc.) is a kinematic intrusion alert technology powered by a carbon dioxide (CO_2) cartridge. The portable, self-contained device requires no electrical power to function. The unit is attached to a traffic cone or barricade at a preestablished interval (based on the work zone configuration and speed limits) along the work zone. The alarm is activated when the traffic cone supporting the unit is tilted. This activation produces an audible alert and indicates where the hazard is emanating from. The device can be attached to different types of traffic cones, including A-frames, security fences, barrels and drums, barricades and delineators (Transpo Industries, 2018). Ideally, devices are attached to every cone (or every other cone) at least 400 ft before the activity zone depending on the cone spacing and speed limit (Kochevar, 2014; Krupa, 2010).

Traffic Guard Worker Alert System

The results from the survey indicated that the Traffic Guard Worker Alert System (WAS) was a popular choice of the respondents who were aware of intrusion alert technologies. It is a pneumatic trigger-based alarm system that transmits intrusion information through a microwave. The system comprises a lightweight visual-audio alarm unit, portable activation hose and an audio-vibratory personal safety device. The 12-ft extendable pneumatic tube is placed alongside the cones around a work zone to create a perimeter that detects intruding vehicles. The audio, flashing light and personal safety device alerts are triggered when an intruding motorist compresses the pneumatic tube (Astro Optics, 2018).

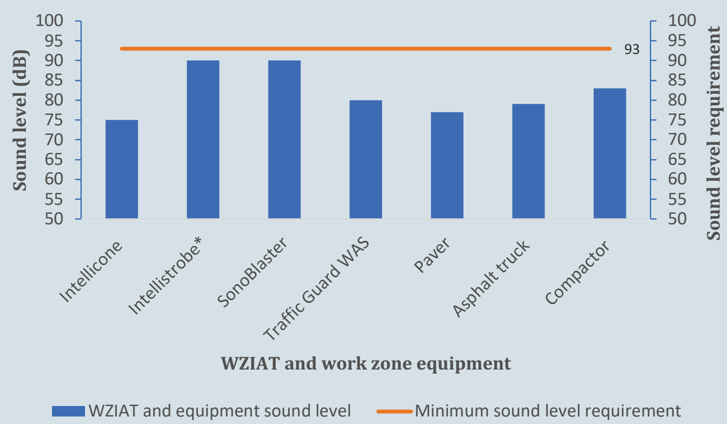
Comparative Analysis of WZIATs & Highway Equipment Sound Level

Due to study limitations, the Intellistrobe technology was excluded from the testing, leaving the research team to focus on three technologies (Intellicone, SonoBlaster and Traffic Guard WAS). Consistent with the results of Novosels (2014), findings from a comprehensive evaluation study sponsored by Oregon Department of Transportation (ODOT) (Gambatese, Lee & Nnaji, 2017) indicate that the SonoBlaster produced the loudest sound (dB) across the different distances measured (Figure 3). Nevertheless, all three technologies evaluated fell below the minimum sound threshold for emergency alarms; the sound produced by an emergency alarm should be at least 10 dB greater than the loudest ambient sound. In this case, the ambient sound came from a nearby pavement compactor emitting 83 dB, therefore requiring a minimum alarm sound level of 93 dB.

Cost Implication

Using a per-mile estimate, the capital costs for covering a 1-mile work zone with Intellicone,

FIGURE 3
Sound Level of Intrusion Alert Technology & Equipment Measured 50 ft Away



Note. **sound level of Intellistrobe has not been substantiated by evaluation study.*

TABLE 3
Summary of FACE Highway Work Zone Fatality Reports

Cause of fatality	FACE recommendations	Preventable by WZIAT?
Sleeping driver struck maintenance worker in work zone (NIOSH, 2001a)	Periodically monitor and evaluate employee conformance with safe operating procedures; adopt policies that require workers to work on the median side of the guardrail; educate the public regarding work zone safety issues.	Yes. Install WZIAT equipped with audio and vibratory alerts approximately 400 ft upstream of worker.
Driver lost control of vehicle and veered into the work zone striking a DOT worker (NIOSH, 2001b)	Consider the use of supplemental traffic control devices; consider installing rumble strips along the roadway pavement edges to warn motorists.	Yes. Equip workers with personal alert systems. Install WZIAT across potential entry points around the work zone.
Flagger struck by secondary contact from truck travelling at 55 mph (NIOSH, 2000)	Consider the use of additional warning signs and traffic control devices; provide and require use of handheld or other portable radio communications equipment by flaggers at all times.	Yes. Implement WZIAT with speed detector and personal alert systems with at least 600 ft transmission distance.

Although past studies indicate considerable limitations of WZIATs, results from a recent study conducted by ODOT indicate that WZIAT has the potential to improve worker safety.

SonoBlaster and Traffic Guard WAS are estimated at approximately $2,400, $1,260 and $5,940, respectively (Gambatese, et al., 2017). Note that the Traffic Guard WAS, unlike the Intellicone and SonoBlaster, is not set up on traffic cones and can provide more comprehensive work zone coverage since the pneumatic tube could be extended along the entire work zone. In addition to capital costs, the operational cost of implementing each technology should be captured to provide a more holistic estimate. The ODOT study provides more information regarding the assessment of WZIAT (Gambatese, et al., 2017).

Benefits

Generally, WZIATs have the potential to improve the safety of construction and maintenance workers in highway work zones. Although the sound produced by the evaluated WZIATs is below the minimum recommended threshold, some manufacturers are upgrading their technology to produce louder alerts. For example, a new version of the Intellicone has been released that includes an adjustable volume control to ensure enhanced auditory alert. In addition to an effective audio alert, a combination of multiple alert sources (i.e., audio, visual and haptic) has the potential to increase the alarm effectiveness and create additional reaction time for workers in work zones. Also, some WZIATs such as the Intellicone are relatively easy to deploy and retrieve thereby creating minimal exposure of workers to roadway hazards and causing minimal interruption to construction operations and work zone mobility. Depending on the project, WZIATs could be considered cost-effective when compared to other work zone safety technologies. Finally, WZIATs such as the SonoBlaster pinpoint the direction of an intruding vehicle.

Technology Limitations

In the limited studies available, several limitations associated with using WZIATs are documented. A primary deficiency reported is the regular occurrence of inaccurate alarms. For one, the SonoBlaster recorded many false positives (alarm produced due to unintentional triggering of the device) during evaluation. In addition, when implemented in mobile operations, traffic control workers are required to continually move the WZIATs as the operation progresses, which could be a daunting task. In certain cases, some WZIATs may not provide sufficient transmission distance leading to reduced reaction time. Regardless of the transmission distance provided, if a motorist breaches the work zone within the activity area at high speed, the WZIAT technology might not be able to provide adequate warning for construction workers. As depicted in Figure 3 (p. 39), the sound produced by intrusion alarms may not be audible over loud background construction noise.

In addition to the WZIATs described thus far, several technologies are in the process of commercialization that have potential to improve the effectiveness of intrusion alert technologies. For example, the Advanced Warning and Risk Evasion system (Artis, 2016) and the Smart Taper and Safelane (Highway Resource Solutions, 2016c) are two promising technologies undergoing evaluation.

Evaluation of Work Zone FACE Reports

Given the limited use of WZIATs on live projects in the U.S., the researchers conducted a comprehensive assessment of NIOSH FACE reports to determine, in retrospect, whether WZIATs could have played a significant role in preventing the reported fatalities. NIOSH reported and evaluated 25 highway work zone related fatality cases from 1984 through 2007. Although 80% of the documented fatalities were primarily caused by workers being struck by equipment, three fatalities occurred due to intruding vehicles.

Table 3 (p. 39) summarizes facts about each intrusion fatality from the FACE reports. As Table 3 shows, using additional work zone safety devices such as work zone intrusion alert technologies could have reduced the chance of the worker fatalities.

Conclusion

Although past studies indicate considerable limitations of WZIATs, results from a recent study conducted by ODOT indicate that WZIAT has the potential to improve worker safety. In addition, the six fatality cases (including introductory cases) presented in this article highlight situations in which implementing a WZIAT could have improved the odds of preventing a worker fatality. Nevertheless, the survey results from the present study indicate that WZIATs are not extensively used as additional work zone safety technologies in highway construction. It is expected that by increasing awareness of the potential benefits of using WZIAT on highway construction projects, project planners could consider including WZIAT in work zone safety traffic control. Future WZIAT products should ensure that the technologies can produce sounds greater than 93 dB within 50 ft in addition to limiting false alarms. The effectiveness of future WZIAT could be improved by increasing the sound produced. It is also expected that future implementation can be increased by increasing the awareness of each technology. **PS**

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Work Zone Intrusion Alert Technologies Studied

The authors studied the four intrusion alert technologies that were commercially available at the time of the study.

Intellicone

Manufacturer: Highway Resource Solutions Ltd., Bottesford, U.K., www.intellicone.co.uk

Demo video: www.youtube.com/watch?v=othcn5eMhW4

Intellistrobe

Manufacturer: Intellistrobe Safety Systems, Springfield, MO, http://intellistrobe.com

Demo video: www.youtube.com/watch?v=tHm4OvCKBQA

SonoBlaster

Manufacturer: Transpo Industries, New Rochelle, NY, www.transpo.com

Demo video: www.youtube.com/watch?v=WRFjerUnNVo

Traffic Guard Worker Alert System

Manufacturer: Astro Optics LLC, Brown Deer, WI, www.astrooptics.com

Demo video: www.youtube.com/watch?v=tXB93yH4mmA