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Advancing safety in short-term utility work zones: Assessing the role of work zone intrusion alert technologies (WZIATs)

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ABSTRACT

Work zone safety is significantly impacted by vehicle intrusions, which are challenging incidents to control. Although the Federal Highway Administration and US state transportation agencies have implemented safety procedures to enhance worker and motorist safety, the rate of intrusions in work zones remains high, necessitating the development of additional solutions. Work zone intrusion alert technologies (WZIATs) have shown promise in highway work zones; however, their application in short-term utility settings remains insufficiently studied. This research aims to characterize the features of intrusion alert systems that can enhance the safety of workers in utility work zones. To achieve this aim, the study adopted a mixed-method design approach, relying on literature review, archival data analysis, experimental assessments, and a case study. The study reveals that motorist/driver behavior is a primary safety risk factor in utility work zone intrusions. Insights from deploying two technologies, AWARE and Alpha SafeNet, in experimental and live utility work zones indicate that an effective WZIAT must be able to alert both drivers and workers, be deployable in less than three minutes, integrate audio, visual, and haptic alarms, have an adjustable warning light, incorporate a pneumatic tube triggering mechanism, and be waterproof. This study contributes to both knowledge and practice by characterizing the safety risks associated with utility work zones and identifying key performance and operational features for deploying WZIATs in short-term work zones.

1. Introduction

Work zones experience different types of incidents which result in fatalities, injuries, and property damage. These incidents occur because of uncontrolled hazards present inside and outside the work zone (Al-Bayati et al., 2023). According to the Fatality Analysis Reporting System (FARS), one of the main risks and reasons for work zone fatalities is vehicle crashes, which resulted in 857 fatalities and 44,240 injuries in the US in 2020 (FARS, 2020). Intrusions and contact with trucks, multipurpose highway vehicles, and passenger vehicles are the leading causes of worker fatalities in active work zones (FHWA, 2007). Fatalities and injuries caused by work zone intrusions remain a vital issue in the utility space despite efforts by FHWA and several state DOTs to propose solutions. For instance, 64 % of highway contractors reported crashes in their construction work zones in 2022 (Work Zone Barriers, 2023). These crashes occurred in different types of work zones, including short term and short duration work zones (Tapan et al., 2016).

In response to the high number of injuries and fatalities in work zones, the Federal Highway Administration (FHWA) and state departments of transportation (DOTs) in the US have developed and implemented different procedures and manuals to improve traffic control in work zones, thereby enhancing the safety of workers and motorists. Although these procedures have helped to improve work zone safety, incidents in work zones still occur at a high rate. Moreover, current traffic control measures and work area protection setups commonly employed, while useful, have not sufficiently protected workers in utility work zones from potentially fatal intrusions (Wang et al., 2013). Utility work zones are classified as short-term stationery (less than 1 day) or short duration (less than 1 h).

To reduce intrusion-related incidents, the use of emerging solutions

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such as intrusion warning devices has been proposed as a risk mitigation strategy (Schneider, 2014). Work Zone Intrusion Alert Technologies (WZIATs) are devices that monitor and detect vehicle intrusions into work zones (Nnaji et al., 2018). These technologies alert workers to an intrusion or potential intrusion, providing valuable reaction time (Nnaji et al., 2021; Khan et al., 2019). Additionally, these devices can warn motorists who are about to encroach into the work zone.

However, WZIATs have primarily been tested and deployed on highway projects with long-term work zones. For instance, studies by Awolusi and Marks (2019), Khan et al. (2019), and Nnaji et al. (2018) evaluated work zone intrusion technologies on highway projects. Currently, limited guidelines are available to support the implementation of these devices in short-term and short-duration utility work zones.

The unique characteristics of short-term and short-duration work zones—such as short work durations, limited traffic control setups, frequent relocations, changing layouts, and the dynamic nature of tasks—expose workers to higher levels of risk (Wang et al., 2013). These characteristics also make it more challenging to deploy certain risk mitigation solutions. Therefore, it is imperative to conduct research to ascertain the potential impact of emerging solutions such as WZIATs in short-term and short-duration applications.

The present study addresses this gap in the literature and contributes to work zone safety research by characterizing the safety risks associated with short-term and short-duration utility work zones, and identifying key performance and operational features for deploying WZIATs in short-term utility work zones.

2. Background

Work zone accident has continued to be a primary cause of injuries and fatalities in the US, reaching a 17-year high in 2021 (Roads&Bridges, 2021). Work zone related fatalities increased by almost 11 % between 2020 and 2021, according to the Federal Highway Authority (FHWA) (FARS, 2022). Recent statistics show that work zone intrusions have increased significantly in 2020 despite reduced traffic volume caused by the COVID-19 pandemic (Work Zone Barriers, 2021; NSC, 2021). The fatalities occurred in different types of work zones, with 479, 56, and 8 deaths reported in construction, maintenance, and utility work zones, respectively (FARS, 2020). The reported fatalities were drivers of motor vehicles (530), pedestrians (156), passengers of motor vehicles (150), bicyclists (14), and others (7) (FARS, 2020). About 15 % of pedestrian work zone fatalities occur in utility work zones (FHTSA FARS, 2019; FHWA, 2020). According to the Center for Construction Research and Training (CPWR), 59 utility workers died in roadway work zones between 2011 and 2016. Furthermore, 15 power-line installers were killed in roadway work zones throughout the same time span, representing an incidence rate of 11.6 fatalities per 100,000 FTEs. This rate was the fourth highest fatality rate for roadway occupations (Wang et al., 2018).

Work zone intrusions pose a significant threat to the safety of workers in an active work zone and are a primary concern for the utility industry. Over the years, the number of work zone intrusions has been increasing. For instance, the number of fatalities caused by intrusions has risen 42 % since 2013 (Work Zone Barriers, 2021). About 80 % of pedestrians (those working in the work zone) were killed by a driver intruding into the work zone (FHTSA FARS, 2019). This class of work zone incidents often leads to high severity outcomes (Bryden and Andrew, 1999; Bryden et al., 2000). For instance, a single intrusion can lead to multiple deaths and extensive property damage.

Intrusions are more challenging to control compared to incidents that emanate from inside the work zone, and traditional traffic control protection methods are not very effective at mitigating work zone intrusion risks, especially in utility work zones (Wang et al., 2013; Schneider, 2014). Utility workspaces present unique challenges for work area protection due to the short durations which are common for utility work, such as electric utility activities. Distracted driving (e.g., using cell phones) and increased speed have become increasingly prevalent and are factors which are critical to the risk associated with working alongside or on the roadway. Other significant risk factors include confusion caused by faulty work zone traffic control set up, ineligible signs, poor road conditions, deprived sleep (fatigue), and consumption of alcohol and drugs (Ullman et al., 2011).

Wang et al. (2013) investigated the effectiveness of traffic control devices within the context of short-term work zones in terms of commanding the respect of drivers, durability, ease of understanding, cost, ease of installation and removal, and reusability. The researchers recommended the use of plastic portable rumble strips, portable changeable message signs, vehicle activated signs, truck mounted attenuators, and mobile barriers to protect motorists and workers in work zones (Wang et al., 2013). Moreover, the research study revealed limitations of using adhesive these system in short-term work zones and recommended additional research within this context.

Previous studies have identified intrusion mitigation technologies that can be used in work zones such as mobile barriers, temporary rumble strips, message boards, vehicle arresting systems, automated flagging devices, rolling roadblocks, and intrusion alarms (Nnaji et al., 2020; 2021). However, Anderson et al. (2016) highlighted that work zone intrusion mitigation needs controls that do not rely on driver assessment and response given that drivers might be impaired. While these mitigation technologies are promising, challenges associated with traffic control setups (e.g., extended time needed for setup and takedown) for utility work zones may impact the successful deployment of these solutions.

2.1. Work zone intrusion alert technologies

Recently, researchers have explored the potential of a new intrusion mitigation solution: Work Zone Intrusion Alert Technologies (WZIATs). These devices monitor and detect vehicle intrusions into work zones, alerting workers to actual or potential intrusions and thereby providing them with valuable reaction time (Nnaji et al., 2021). Since 2016, numerous studies have examined the effectiveness of these technologies. For instance, researchers evaluated the effectiveness of SonoBlaster, Traffic Guard Worker Alert system (WAS) and Intellicone (Awolusi and Marks, 2019; Nnaji et al., 2018). These studies showed that these technologies produce more than multiple alarms used to warn workers of an intrusion incident. The researchers reported a satisfactory result regarding power consumption and battery performance, easy set-up of the technologies, and limited false alarms, while further testing in different scenarios was recommended to document additional benefits and limitations of these technologies. Sanni (2019) also evaluated the effectiveness of several work zone intrusion technologies through focused testing of the technologies. The WAS exhibited good performance with some restrictions, the Sonoblaster system presented several challenges related to its use and effectiveness that could not be resolved, and the Intellicone system performed well after consulting with the manufacturer.

While most WZIATs are designed to warn workers after an intrusion occurs, a few have the potential to proactively inform both workers and motorists of an impending intrusion. Currently, two intrusion alert devices—the Advanced Warning and Risk Evasion (AWARE) system and Alpha SafeNet Overwatch—have shown significant promise as proactive warning systems.

2.1.1. AWARE

The AWARE system is a radar-based advanced warning system developed to detect intrusions using the speed of vehicles heading toward the work zone (Fig. 1). The technology developers have created two versions of the AWARE system. The first version is designed to detect work zone intrusions and is called “lane intrusion.” The second version, called Sentry, is primarily intended for use by flaggers. Although both systems use the same components, there is a key

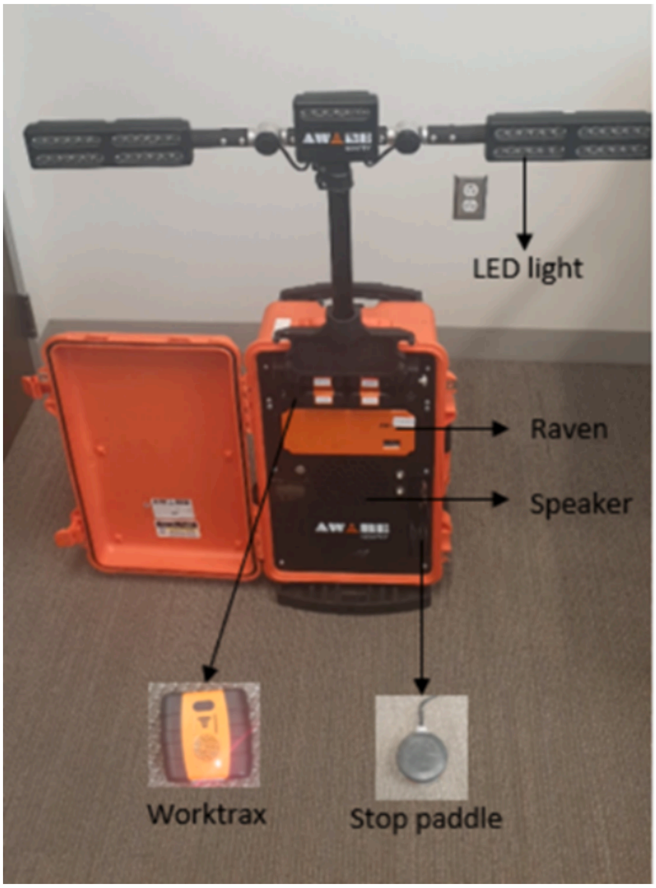
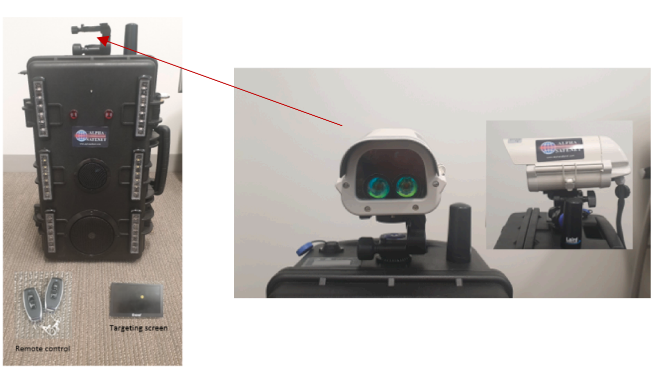


Fig. 1. AWARE system.

difference between the two. The lane intrusion system can be mounted on moving vehicles and equipment, while the Sentry is kept fixed in a hard case at a location. During testing for the present study, only the Sentry was available to the researchers and considered for further assessment (Mishra et al., 2021).

2.2.1.2. Alpha SafeNet Overwatch. Alpha SafeNet Overwatch is a LiDAR-based technology. The system is available in two versions. The first version is equipment-mounted and the second version is portable (Fig. 2). The difference between the two systems is that the mounted system can be placed at working vehicles, while the portable system is placed on the alarm unit. During testing, only the portable version was available to the researchers and this version was selected for further assessment. The portable overwatch device is placed on the roadside in



(a) (b)

Fig. 2. (a) Alpa SafeNet Base device (b) Mounted LiDAR system.

case of traffic disruption due to the work zone setup. Once activated, the system creates an invisible electronic barrier (laser line) that runs straight, shielding the work zone or traffic incident location. If a vehicle crosses the electronic barrier represented by the laser line, the Overwatch technology triggers a flashing light and horn alarm to warn the driver and workers. If the driver notices the alarm and makes the necessary correction, the alarms (horn and flashing light) stop. Furthermore, workers present in the work zone are alerted about the intrusion and can swiftly take action to avoid being struck by the intruding vehicle.

A summary of notable features and recommended deployment strategies for the AWARE and Alpha SafeNet Overwatch systems are presented in Table 1.

2.2. Research need

Work zone intrusion incidents are one of the main risks affecting work zone operations in the construction industry. Studies have investigated the major factors causing these types of incidents, and recommended some mitigation strategies over the last decade with the goal of improving work zone safety. Although short-term utility work zones are facing several safety challenges, very limited studies have investigated these concerns or proffered solutions that are specific to their characteristics in terms of the work type and duration.

Short-term work zones, such as utility operations, require special attention in comparison to long-term work zones like highway construction and maintenance operations. These zones typically occupy only a section of the roadway or sidewalk, with their layout often changing rapidly due to the nature of the work, such as moving equipment or repositioning barriers (Datta et al., 2008). Crews in short-term work zones are frequently relocated as they move from one site to another to address various issues or projects. Activities in short-term work zones, such as utility work, often involve emergency response situations, like repairing or restoring power after an outage, necessitating quick setup and efficient management of work zones. Due to their short duration and small size, utility work zones may have limited traffic control measures compared to larger, long-term road construction projects, with traffic control devices and barriers often being temporary and

Table 1
AWARE and alpha SafeNet features and capabilities.

Technology	AWARE	Alpha SafeNet
Manufacturer	CRH America Materials,Inc.	ALPHA SafeNet
Weight	50 lbs.	35 lbs.
System Components	(i) A unit that produces alerts comprising a sensor based on radar technology, flashing LEDs, and audio alarm. (ii) Personal alarms called Worktrax.	(i) A unit that produces alerts comprising sensor based on LiDAR technology, flashing LEDs, and audio alarm. (ii) Small alarm unit that produces flashing light and audio alarm.
Alert Mechanism	Radar sensor tracks vehicle speed and trajectory and uses stopping sight distance calculations to determine the suitable alarm.	The system creates an invisible laser line that runs straight, shielding the work zone. If a distracted driver crosses this barrier, the technology triggers a flashing light and horn alarm to warn drivers and workers
Type of Alarm	The sensor unit produces sound and flashing LED alerts, while the personal alarms have vibratory and sound alerts.	The alarm main and small units produce sound and flashing LED alerts.
Deployment	The primary unit is positioned on the roadway shoulder outside the transition taper and facing the traffic heading towards it, while the workers carry personal alarms.	The primary unit is positioned on the roadway shoulder outside the transition taper and facing the traffic heading towards it, while the small unit is placed near workers inside the work zone.

easy to set up and remove quickly.

These unique characteristics of short-term work zones create traffic control challenges. The frequent movement and relocation required in short-term work zones necessitate intrusion alert systems that are highly mobile and easy to redeploy, complicating the setup and calibration of these systems. Moreover, these systems must be designed for rapid deployment and removal without compromising their effectiveness. The limited space available in short-term work zones makes it challenging to deploy extensive intrusion detection infrastructure, requiring compact and versatile systems. Given that the layout and boundaries of short-term work zones can change rapidly, the intrusion system used in this context must quickly adapt to new configurations without extensive recalibration.

A detailed review of existing studies revealed limited work zone safety risk assessment studies focused on utility work zones. Previous WZIAT evaluations focused on highway work zone conditions and applications (Khan et al., 2019; Nnaji et al., 2018), ignoring the distinctiveness of other types of work zones. Besides, very few studies have evaluated the potential impact of proactive WZIATs, and previous WZIAT studies (Awolusi and Marks, 2019; Nnaji et al., 2018; Thapa and Mishra, 2021; Khan et al., 2019; Ullman and Theiss, 2019; Martin et al., 2016; Mishra et al., 2021) did not consider two distinct conditions – (1) at an elevation and (2) within an intersection – when evaluating the performance of WZIATs in controlled settings.

Studies of utility work zones are needed to answer questions about the primary safety risk factors that cause work zone intrusion incidents in utility work zones and available mitigation technologies that could be used to mitigate these risks. Considering the significant safety challenges in utility work zones and the lack of information on WZIAT applications within this context, there is an urgent need to explore the potential impact of WZIATs on worker safety within this context. Therefore, the objectives of this study are to:

Identify key safety risks associated with intrusions into utility work zones.

Evaluate the performance of intrusion alert devices within utility work zones.

Characterize the necessary features of technologies aimed at mitigating intrusions in utility work zones.

3. Research methodology

The research team adopted a mixed-methods approach that consisted of a literature review, archival analysis, interviews, controlled/experimental testing, and a case study.

3.1. Identification of safety risk factors and WZIATs

A qualitative approach consisting of a scoping literature review and archival analysis was used in the study to identify the safety risks associated with electric utility work zones. The literature review involved a search of the available academic and grey literature using different online search engines and databases containing work zone intrusion incidents. The main databases searched were Transportation Research International Documentation (TRID) and the National Work Zone Safety Information Clearinghouse (NWZSIC), both of which are recommended sources for transportation and work zone research (Nnaji et al., 2020). In addition, the researchers performed a search in available archival incident databases, such as those overseen by the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH), using keywords related to work zones. The searches were conducted to identify the documented work zone intrusion incidents. Given that NIOSH reports a subset of cases captured in the OSHA database, the researchers reviewed each case and removed those that were redundant (appeared in both OSHA and NIOSH databases). The incidents were then analyzed to determine the main safety risk factors that led to the incidents. Based on this analysis, the unique identified safety risk factors were placed in a risk register and analyzed in terms of frequency of occurrence and their relation to utility work zones, if applicable. More than one risk factor could be identified with a single incident case. By completing this step, a risk register summarizing the main risk factors that cause work zone intrusion incidents in general and especially for utility work zones was developed which helped identify technologies that can mitigate the primary safety risks.

Subsequently, the researchers identified WZIATs published in existing literature on previous studies. WZIATs are devices that monitor work areas, detect vehicle intrusions into work zones, and alert workers when an intrusion occurs. A few studies have evaluated WZIATs in different applications, however, some WZIATs have not yet been evaluated at this time. The research team streamlined the identified WZIATs based on cost, availability, ease of use, possible implementation/integration into traffic control plans, and the technology's potential to enhance worker safety in utility work zones (mitigating the safety risks identified in the literature review and archival data analysis).

3.2. Verification of safety risk factors and appropriate WZIATs

The research team conducted semi-structured interviews of utility company personnel to collect data regarding current work zone practices and policies, high-risk work activities, and perceptions of work-zone intrusion technologies. Twenty-three safety professionals across six organizations volunteered to participate in the semi-structured interviews. These companies operate in various locations around the United States and range in size from small to large with respect to number of employees. Further detail on the interviewees' companies can be found in Table 2. Interviewee position titles included field safety manager, corporate safety manager, operations manager, and crew leader. The interviews were not limited to short answer responses; rather, participants were asked open- and closed-ended questions and provided sufficient time to ask questions about the study and share any additional thoughts or comments they may have. Interviews were conducted online via Zoom and/or Microsoft Teams.

The interviews included a combination of single person interviews and group interviews. Each interview lasted approximately one hour. The interviews were audio and video recorded and Microsoft Word was used for real-time transcription of the audio recordings. The real-time transcripts were then checked for accuracy following the interview.

Qualitative analysis was performed using the interview transcripts. The transcripts were initially uploaded to an analysis software (NVivo version release 1.5.1), which allowed for an iterative review process. Then, several top-tier codes (i.e., key words used to capture themes present in the interviews) were created in the software. The codes were based on the interview questions asked and researcher perceptions of common trends. Each transcript was highlighted in the software based on the top-tier codes. The codes were selected to determine which technologies are currently being used by utility companies and which technologies are of interest. There was also a focus on high-risk activities, current practices and procedures, and general concerns regarding the implementation of work zone intrusion technologies. "Children"

Table 2
Company overview.

Company	company size	Company location	# of participants
A	Large	United States, Canada	4
B	Medium	Northeast US	2
C	Large	Northeast US	4
D	Small	Arkansas	1
E	Medium	Michigan	3
F	Large	Midwest US, Southern US, Northeast US	7

codes were created after patterns from the top-tier codes were identified. The children codes highlighted further details provided by interview participants, and included technology specific concerns and applications and information on the use of law enforcement for traffic control.

3.3. WZIATs assessment

The selected technologies were initially tested under controlled, off-roadway conditions in a secure location that was not exposed to public traffic. These tests facilitates the comprehension of WZIAT features, their strengths, weaknesses, and the implementation process for each technology. The test results could be utilized to ascertain the feasibility, capabilities, and limitations of each technology. The researchers conducted experiments at the Texas A&M Transportation Institute (TTI) Proving Ground facility located on the Texas A&M RELLIS Campus using three different vehicles – a sedan, an SUV, and a truck. The researchers created several scenarios that mimicked utility work zones described in fatality reports. Each of the selected technologies was assessed to capture its capabilities in terms of: (1) level of audible alerts; (2) transmission range, and (3) false alarms. The technologies were rated based on quantitative data collected by the research team using different data collection techniques (e.g., sound meter).

The noticeability of sound alarms depends heavily on the intensity and characteristics of the sound alerts relative to the ambient noise level in the surrounding environment. To determine the intensity of sound alerts produced by the WZIATs, a sound meter, REED R8080, was used to measure the sound produced by the WZIAT. The sound meter was held at a height of 3 ft above the ground at different distances from the alarm devices. The testing criteria (e.g., sound level) were measured across distances that varied from 0 ft (at source) to 500 ft in approximately 50 ft increments. Three readings for sound intensity were taken at each interval/increment. To determine if the orientation of the alarms affected the intensity of the alerts produced, sound intensity was measured from five different directions by changing the alarm's orientation. The test started with the researchers measuring the sound at the source by pointing the sound meter at the speaker (south direction).

Previous research has indicated that the construction industry faces a significant challenge in implementing and adopting WZIATs due to the relatively high likelihood of false alarms (Nnaji et al., 2020; Burkett et al., 2009; Nnaji et al., 2021). To address this issue, the research team conducted a controlled experiment in which each WZIAT was triggered at least 10 times per condition/scenario. The focus was on assessing the frequency of false negatives (the device failing to produce an alarm when it should). In addition, the research team observed and recorded any false positive (the device produces an alarm when it should not).

In addition to scenarios explored in previous studies (Awolusi and Marks, 2019; Nnaji et al., 2020), the present study considered two distinct conditions not covered in previous research – (1) at an elevation (Fig. 1) and (2) within an intersection (Fig. 3) – when evaluating the performance of WZIATs in controlled settings. The research team assessed the potential of each technology to detect an intrusion along eight paths as shown in Fig. 1. Given the nature of the Alpha SafeNet triggering mechanism, the device was placed in three different locations (Fig. 3b).

Subsequently, the team evaluated the potential impact of elevation on the effectiveness of WZIATs by simulating a work zone at an elevation, as shown in Fig. 4. To evaluate the potential impact of a difference in elevation on the performance of the intrusion alert devices, the research team identified an elevated location at the TAMU Proving Gound (approximately 6 feet difference in elevation at the highest point). As shown in Fig. 4, the devices were placed at the highest and lowest point while the approaching vehicle started at the opposite location (e.g., the vehicle starts at the lowest elevation point if the device was placed in the highest elevation point).

The transmission range refers to the maximum distance or area within which the technology components can communicate with each other. The range is an important consideration when implementing intrusion alert technologies because it determines the coverage area or work zone length that can be effectively served by the technology (Nnaji et al., 2018). The coverage area is crucial to consider when selecting systems because technologies designed for work zone applications may

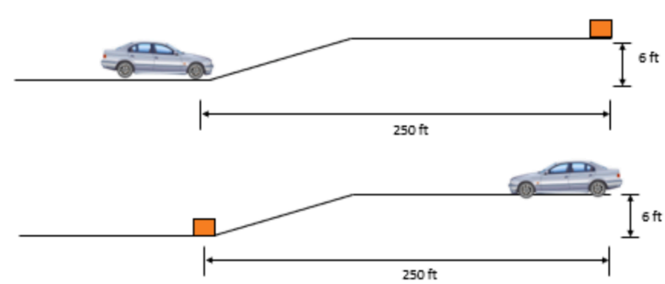


Fig. 4. Device and vehicle at different starting elevations.

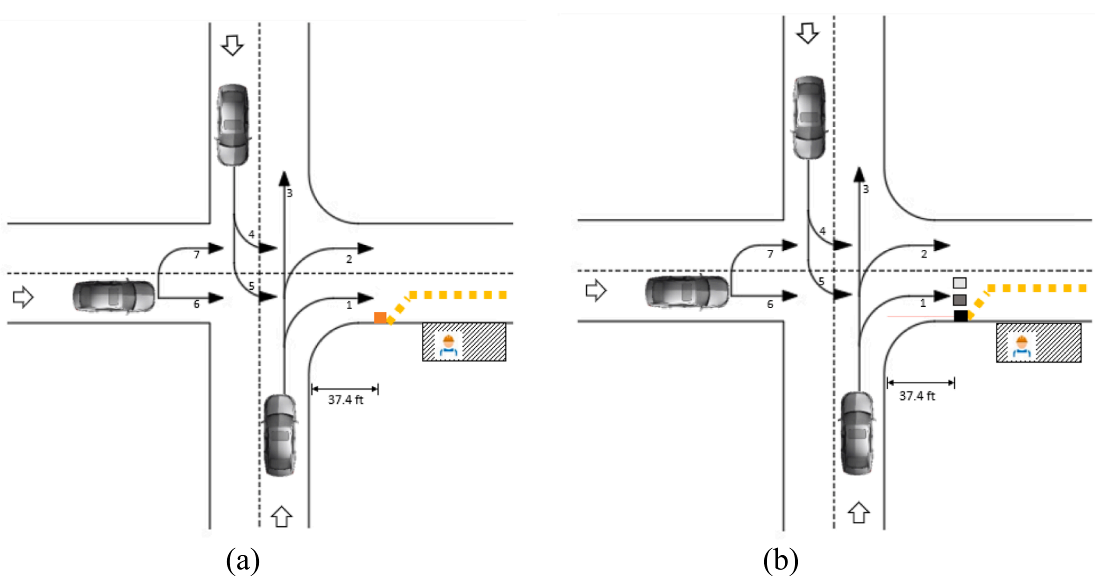


Fig. 3. Approaching WZIAT at an Intersection (a) AWARE (b) Alpha SafeNet.

become ineffective if used in work zones that exceed their transmission range. The objective of this experiment was to ascertain the transmission range of different components for selected technologies. The research team also evaluated how much is needed to deploy and remove the WZIATs.

3.4. Evaluation of WZIATs and extraction of key features

Following the completion of the controlled test, the subsequent phase involved the practical application of the two targeted technologies (AWARE and Alpha SafeNet) within a live utility work zone project. The primary objectives behind deploying the technologies in a real-world project were threefold: (1) introduce the innovations to industry professionals, allowing them to gain firsthand experience with the technology; (2) solicit feedback and comments from industry experts regarding the technology's performance and potential enhancements; (3) assess reactions of individuals working in the presence of the technologies to develop critical insights into their practical value and impact within the context of utility work zones.

The research team conducted a focus group meeting with the workers at the project site to explain the deployment and use of each technology. Eighteen workers participated in the meeting, and it included a demonstration showing the triggering mechanism for each technology. Immediately following the orientation, a survey was sent out to the participants seeking feedback on the technologies prior to their deployment in the work zone. The deployment, use, and removal of the technologies was monitored by the research team on a live project (Fig. 5), in addition to the use and movement of the workers in the presence of the technology. Afterwards, the workers were interviewed to obtain and record their feedback about the technology and its effect on their safety. The data collected from the case study provides insight on the feasibility, obstacles, facilitators, and expected impact of each technology. In addition, the data helps create recommendations for ideal features of future WZIAT for utility applications.

4. Results and discussion

4.1. Work zone intrusion safety risk assessment

The literature review revealed that few studies have focused on short-term, short-duration work zones, with no studies on utility work zone safety. Nine articles discussed risk factors associated with work zone intrusion incidents based on analysis of archived data including DOT reports. However, none of these articles was comprehensive in terms of the case descriptions and the studies were primarily limited to a certain geographical region (e.g., in New York or California). Therefore, a comprehensive archival search for and review of work zone intrusion incidents in available OSHA and NIOSH databases was conducted to identify the main risk factors leading to work zone intrusion accidents and analyze risk factors in terms of frequency and relation to utility work zones. Overall, 440 work zone-related incident cases were analyzed, and 219 of the cases were related to work zone intrusions. Forty-nine cases involving utility work zones (electric and others) were found in the databases, as shown in Table 3. Fifteen of these cases (30.1 %) were classified under work zone intrusions (incidents involving an intrusion), as depicted in Table 4.

Thirteen primary work zone intrusion risk factors were identified and grouped into six categories: (1) Motorist/Driver, (2) Vehicle, (3) Roadway/Environmental Condition, (4) Work Operation, (5) Worker, and (6) Other. As shown in Table 4, approximately half (50.32 %) of the identified work zone intrusion incidents resulted from motorist/driver actions (e.g., impaired or distracted driver), and work operations and roadway/environmental conditions were each associated with approximately 6 % of the incidents. The primary risk factor for approximately 30 % of the reviewed reports could not be determined from the information provided. The top five Motorist/Driver risk factors, based on the number of occurrences, were: (1) vehicle trajectory, (2) vehicle speed, (3) driver condition (e.g., impaired and sleeping drivers), (4) driver awareness, and (5) driver behavior. For electric utility work zones, the primary risk category was Motorist/Driver (67 %), followed by Work Operation (20 %). Table 5 summarizes the risk factors at the group level.

Results from the interviews supported the findings from the archival analysis and literature review. For example, an interview participant

Fig. 5. Live project work zone set-up.

Table 3
Work zone incidents in OSHA and NIOSH databases – By type of work.

Database	Total related cases	Type of work				
		Highway constr. & maint.	Utilities	Landscaping	Building works	Other / Type of work not reported
OSHA	344	190	38	12	4	100
NIOSH FACE Reports	96	80	11	1	–	4
Total	440	270	49	13	4	104

Table 4
Work Zone Incidents in OSHA and NIOSH Databases – Location of risk.

Database	Total related cases	Location of Risk			
		Intrusion into work zone	Outside the Work Zone	Inside Work Zone	Other / location not reported
OSHA	344	191	47	77	29
NIOSH FACE Reports	96	29	5	61	1
Total	440	220	52	138	30

stated, "*… for the most part, any work that we do to repair the [electric utility] system is going to put us at risk because it's all done along the roadway.*" However, there were several cases and activities which were discussed in greater detail and noted to put utility workers at the greatest risk of being struck by an errant vehicle. For instance, flagging activities were noted by almost every participant interviewed as a high-risk activity. Most participants stated that flaggers are at the highest risk of injury amongst anyone in a work zone because they are at the front of the work zone. Thus, flaggers would be the first person in harm's way if a vehicle were to intrude into the work area protection setup. Single person work (i.e., a worker working alone) was also noted as a high-risk activity because there is typically no work area protection around the sole worker. Single person work includes activities such as checking meters or performing inspections.

Most other concerns regarding work zone intrusions stemmed from roadway geometry and vehicle speeds. Several interviewees mentioned that there is often more risk involved with working in rural areas. Hazardous conditions identified include work on two-lane roadways with speeds from 40 to 55 miles per hour, and mountainous roadways, curves, and non-interstate speed highways. Additionally, work performed near intersections or parking lots was considered high risk. Lastly, weather conditions and time of day could affect the amount of risk associated with utility activities. For example, in rain, snow, or icy conditions, a vehicle is more likely to lose control and enter a work zone. Low light conditions can also cause visibility problems which may lead to an intrusion. Overall, high risk activities vary based on location, timing, roadway design, and weather conditions. Because of the nature of utility work, most activities are at risk of experiencing a work zone intrusion. This exposure puts every utility worker in danger of being struck by an intruding vehicle.

4.2. Work zone intrusion alert technology selection

The interviewees also provided their perspective regarding the use of WZIAT in work zones. In general, study participants noted willingness to pilot WZIAT in their work zones. However, implementation of these technologies did not come without concerns. First, ease of deployment is an important factor in selecting a technology. Utility work is often short duration, lasting anywhere from 30 min to several hours. Any technology used for work zone mitigation must be deployed and retracted quickly – preferably in under three minutes – to ensure that the work duration is longer than the deployment process. If the deployment of the technology is not efficient, workers may be exposed to more risk by setting up traffic control measures than by performing the electric utility activity.

Second, cost is a factor which must be considered in the implementation of a new technology. While most of the interviewees stated that cost would not be "hugely prohibitive," smaller companies may need to consider this on a deeper level. This is due to an avoidance of raising service process, such electric power prices, for consumers. However, all companies stated that with proper documentation and rationale, cost could be irrelevant.

Third, availability of resources is a big concern for utility companies when choosing to pilot a new technology. Resources could include physical materials, storage space on bucket trucks, and manpower. Several interviewees noted that storage space on bucket trucks is limited already, so crews may push back a bit when asked to add another traffic control technology to the already cramped truck. In addition, employees from company F stated, "*The crews are limited enough as it is. We don't have the extra manpower to drive extra vehicles and extra equipment around.*" Alongside manpower, physical resources may be lacking. There may not be enough devices to deploy with every crew, so some workers may be hesitant to adopt the technology. If the crews cannot use the technology for every job, they may choose to not use the technology at all.

Fourth, participants highlighted the need for WZIAT to work effectively in practical situations such as at different elevations and close to roadway intersections. Unfortunately, little to no data is available on how intrusion alert systems perform in these conditions.

Based on the list of identified commercially available WZIATs, and the adoption factors described above, the Advanced Warning and Risk Evasion (AWARE) system and the Alpha SafeNet Overwatch were found to meet most of the desired criteria: providing an advanced warning to the driver and worker before an accident occurs.

4.3. Controlled tests of selected WZIATs

As described in Section 2, experiments were conducted to evaluate the efficacy of selected technologies within a controlled environment.

Sound level: The ambient noise level was approximately 55 dB. Fig. 6 shows a comparison of the sound levels measured for the different orientations at different distances. The sound level was consistently higher when measured in facing the speaker and when the device was oriented towards 45-degree. It should be noted that the speaker is located on the south side of the AWARE and Alpha SafeNet systems.

Additional trials were conducted to measure the sound level inside the approaching vehicle to determine if the sound level is perceptible to the driver. According to Murphy and King (2022), a 3 dB increase is just noticeable, a 5 dB increase is clearly perceptible, and 10 dB increase is perceived twice as loud relative to the initial noise level. The SUV was used for this measurement, and the vehicle stopped at 100 ft interval distances between the starting point and maximum distance (500 ft). The sound level inside the vehicle was 42 dB when the vehicle was idling (engine and AC on). The results presented in Fig. 7 highlight the measurements from inside the vehicle when the AWARE and Alpha SafeNet systems were triggered, respectively. As shown in the tables, the effect of triggering the AWARE and Alpha SafeNet systems (increase in dB) was noted the most when these devices were triggered 100 ft away and the effect declined as the distance increased.

Triggering Range: The maximum work zone speed limit (speed limit that triggers AWARE) at which AWARE could be set was 45 MPH.

Table 5
Work Zone Intrusion Risk Factor Groups (n = 440)*.

Risk category/ Level I	Risk factor level II	Risk element/ Level III	Frequency
Motorist/Driver	Driver behavior	Swerved from travel lane	21.00 %
Motorist/Driver	Vehicle speed	High speed	10.96 %
Motorist/Driver	Driver condition	Impaired drivers	7.76 %
Motorist/Driver	Driver awareness	Distracted drivers	2.74 %
Motorist/Driver	Driver behavior	Warning signs ignored	2.28 %
Motorist/Driver	Driver condition	Sleeping drivers	1.83 %
Motorist/Driver	Driver behavior	Vehicles backing up	1.83 %
Motorist/Driver	Driver behavior	Vehicle yield failure	0.91 %
Motorist/Driver	Driver behavior	Overtake on the right	0.46 %
Motorist/Driver	Driver behavior	Drive in wrong direction	0.46 %
Work Operation	Quality of traffic control implementation	Poor sign installation/removal	2.28 %
Work Operation	Quality of traffic control implementation	Poor lighting	1.37 %
Work Operation	Quality of traffic control implementation	No warning signs installed	1.37 %
Work Operation	Quality of traffic control implementation	Mobile operation without TMA	0.46 %
Work Operation	Quality of traffic control implementation	No flagman is posted	0.46 %
Work Operation	Quality of traffic control implementation	Work zone unrecognized	0.46 %
Roadway/ Environmental condition	Roadway objects/ infrastructure	Objects close to work zone	2.28 %
Roadway/ Environmental condition	Roadway visibility	Obscured vision	1.83 %
Roadway/ Environmental condition	Roadway design	Road geometry impedes driving performance	0.91 %
Roadway/ Environmental condition	Roadway objects/ infrastructure	Exposed to roadway objects/ infrastructure	0.46 %
Roadway/ Environmental condition	Roadway condition	Wet pavement	0.46 %
Vehicle	Vehicle condition	Objects de-attached from passing vehicles	1.83 %
Vehicle	Vehicle condition	Vehicles mechanical problems	1.37 %
Worker	Worker behavior	Traffic controller not following safety rules	0.91 %
Worker	Worker behavior	Standing behind/near traffic control devices	0.46 %
Worker	Worker behavior	Poor communication	0.46 %
Other	Accident distance from work zone	Accidents near work zone	2.74 %
Uknown	Uknown	Uknown	29.68 %

*an incident case could include more than one risk.

Consequently, the work zone speed limit was configured at 45 MPH. Throughout the 10 tests, AWARE consistently triggered at distances between 450 and 500 ft. An additional trial was conducted at a speed of 65 MPH, which did not impact the triggering range (remained between 450 and 500 ft). Based on the conducted tests, the maximum triggering range of AWARE was determined to be approximately 500 ft. The maximum distance for the Alpha SafeNet was determined to be 300 ft when targeting the LiDAR line against a traffic cone and barrel. The device failed to trigger when tested 350 ft and 400 ft away from the device. Subsequently, a larger object (F-150 truck) was employed for targeting, which proved successful at distances of 300 ft, 350 ft, 400 ft, 500 ft, and 550 ft. Beyond that range, targeting failed at 600 ft and 650 ft. Consequently, it was concluded that using larger objects such as cones, barrels, and trucks can enhance the target distance and simplify the targeting process.

Transmission Range: The transmission range between the main AWARE alarm unit and the personal safety device (Worktrax) was assessed in front of the device by standing at a certain distance away from the main alarm unit and triggering the device using the mobile application to check the maximum transmission range between the base unit and the Worktrax. The maximum distance recorded was 850 ft when measured in front of the device. A distance up to 150 ft was confirmed behind the device as well. As for Alpha SafeNet, the transmission range between the main alarm unit and secondary unit was assessed in front of the device by standing at a certain distance away from the main alarm unit, and triggering the device by crossing the LiDAR line (waving in front of the laser, for instance) while it is in the target mode. The maximum recorded distance was 900 ft.

False Negative Alarms: The AWARE system successfully triggered every time (10 out of 10 trials; 100 % success) for the different setups. Similar trials were performed at higher vehicle speeds for the different work zone limits using three different vehicles, and the same result was noted (100 % success). The Alpha SafeNet did not produce any false negatives as well (100 % success) when triggered multiple times. The smaller alarm unit was successfully triggered, and each time it was triggered, the secondary unit produced visual and audio alarms.

False Positive Alarms: When performing the false negative alarm testing, the researchers took note of any potential false positive alarms. All alarms generated during the false negative tests were a result of actual triggering events; therefore, no false positives were recorded. However, for the Alpha SafeNet device, two false positive alarms were recorded. These false alarms were produced because of the inability of the technology's triggering mechanism (targeted LiDAR line) to differentiate between low or no risk events and high-risk events. The alarm triggers once the LiDAR line is disrupted by humans, animals, or an object.

Scenario I: Intersection

The AWARE system was successfully triggered 57 % of the trials for the different intersection scenarios (4 out of 7 scenarios). The results were the same regardless of the vehicle used (SUV, truck, and sedan) and the device position (outside edge, center, and inside edge of the lane). Each condition was verified five times. The system was not expected to trigger in one of the scenarios – Path 3 – and triggering would have been considered a false alarm. The device did not activate when vehicles drove by the protected work area following path 3, thereby highlighting the device effectiveness. However, the AWARE system failed to trigger when vehicle approached the work zone around a bend/curve. The Alpha SafeNet system sounded an alarm in four out of seven paths assessed (57 %) for the intersection scenarios. Similar to the AWARE system, the results were the same regardless of the vehicle used (SUV, truck, and sedan) and the device position (outside edge, center, and inside edge of the lane). Each condition was verified 9 times, and Table 6 summarizes the results.

Scenario II: Elevation

Device at low position/elevation: The AWARE triggered successfully when using the SUV, sedan, and truck for all five trials for each of the different speeds tested. However, the triggering range was negatively impacted (i.e., decreased) at higher speeds due to the technology's limited vision/reach at lower elevation. Alpha SafeNet triggered successfully for each of the different speeds tested. The triggering range was negatively impacted (decreased) with the vehicle size (i.e., as the vehicle

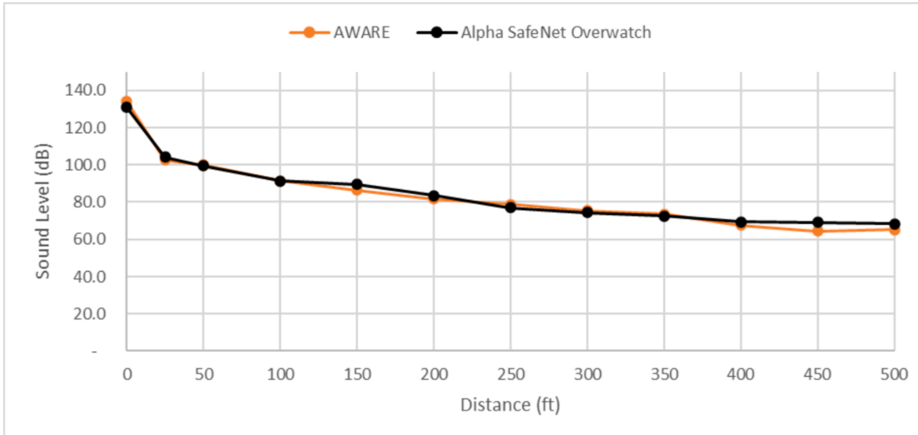


Fig. 6. Sound level relative to distance.

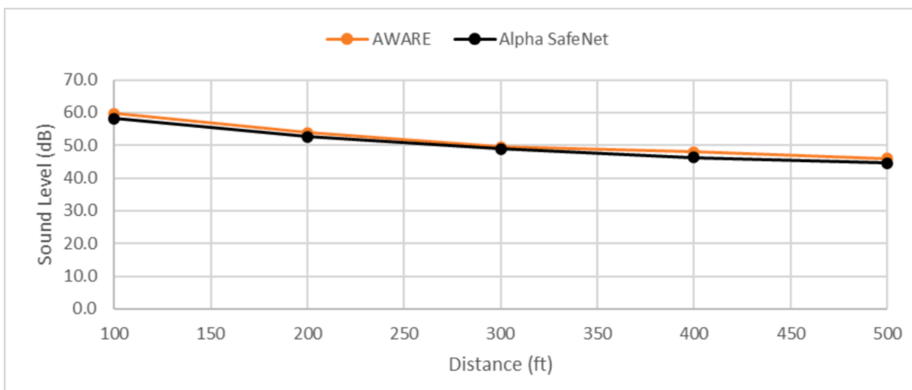


Fig. 7. Sound level inside the vehicle.

Table 6
Triggering rate at roadway intersections (n = 9).

Path no.	WZIAT	Success Rate	Remarks
1	AWARE	0 %	
	Alpha SafeNet	100 %	
2	AWARE	0 %	
	Alpha SafeNet	100 %	
3	AWARE	0 %	Considered a false positive if triggered for this path
	Alpha SafeNet	0 %	
4	AWARE	100 %	
	Alpha SafeNet	0 %	
5	AWARE	100 %	
	Alpha SafeNet	100 %	
6	AWARE	100 %	
	Alpha SafeNet	100 %	
7	AWARE	100 %	
	Alpha SafeNet	0 %	

size decreased, the triggering range also decreased). Placing the device on the truck bed did not improve (increase) the triggering range, on the contrary; the range decreased.

Device at high position/elevation: The AWARE triggered successfully when the vehicles approached the device at different speeds. The triggering range for AWARE consistently performed better with approach speeds between 25 and 45 MPH when placed at an elevation compared to when positioned at the lower elevation. The Alpha SafeNet triggered successfully when each vehicle was used with different approach speeds. However, the triggering ranges were less than the values recorded when the device was placed at the lower elevation. This result is likely because the level of the LiDAR line is higher than the vehicle's height until the vehicle approaches a point in the inclination where the laser can detect the vehicle.

4.4. Live project tests

The live project evaluation involved a demonstration, focus group, and deployment on a live project. Following the demonstration, the researchers engaged the 18 participants in a discussion focused on the applicability of the WZIATs into their work process and the features of an ideal WZIATs. Some of the key features mentioned were *sufficient reaction time, alert drivers and workers, limited time for deployment and removal, simple and robust technology, and availability of vendor for repairs*. After the discussion with the participants, they were asked to complete a survey questionnaire to measure their perception toward the WZIAT using five criteria – ease of use, ease of integration, sound effectiveness, light effectiveness, sound distinction, and alert noticeability by driver. Half of the participants (9 of the 18 workers) completed the survey. The five-point Likert scale ranged from very difficult/ineffective/indistinctive/unnoticeable (1) to Very easy/effective/distinctive/noticeable (5), with the middle point (3) indicating neutral. The survey results are based on median values and summarized in Fig. 8.

As shown in Fig. 8, participants rated both technologies identically

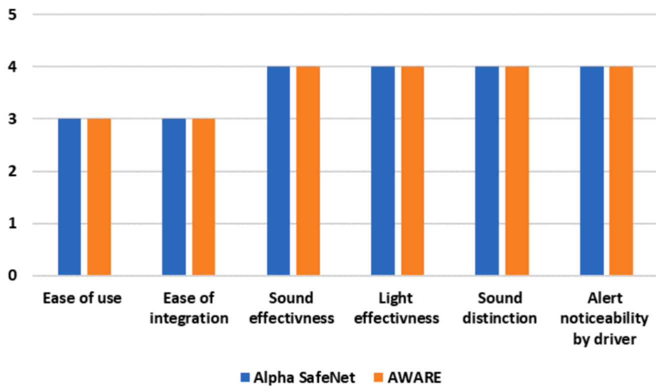


Fig. 8. Survey results (n = 9).

across the five assessment criteria. Most participants were not certain of the level of effort needed to use and integrate these WZIATs into their practice. However, they believe that the alerting mechanisms used to alert workers and drivers are effective.

Throughout the day, the WZIAT remained activated and detected four vehicles entering the work zone, all affiliated with the project. The research team closely observed the workers' reactions during this period, noting their attentiveness to the audible alerts and their inclination to glance in the direction of the traffic. When the intrusion events occurred, the workers' responses were notably positive, as they promptly directed their attention towards the traffic and source of the sound, in accordance with expectations. The findings from the live test reveal that workers believe the technologies are useful in utility operations, especially in non-mobile operations. Alpha SafeNet recorded a 100 % triggering rate (no false positive or negative) while AWARE was not deployed as part of the work operation.

5. WZIAT required features and practical insights.

Based on the findings obtained from the literature review, archival data analysis, pilot and live tests, and surveys conducted in this study, the researchers compiled a list of critical features that a WZIAT should possess for enhanced effectiveness and safety in utility work zones. These features are summarized in Table 7. These recommendations aim to optimize WZIAT functionality and address specific challenges encountered in the context of utility work zones.

5.1. Alert system

WZIATs should at least have a combination of audio and visual alarms as the work conditions in utility work zones could impede the effective transfer of either alert mechanism. Relying solely on visual alerts may be insufficient in daytime work, and relying solely on audio alert may be insufficient in a very noisy environment. Furthermore, WZIATs should have the ability to add personal safety devices and additional alarm units that could be carried around by the workers or placed beside them. This feature will provide additional safety protection, especially in environments where the workers are far from the main unit, or the work generates sound levels above 90 dBA and it is difficult to hear the main unit alarm. Haptic/vibration alert via a personal device provides an additional layer of protection for workers who are wearing hearing protection devices due to their exposure and proximity to sources of excessive noise. Workers focused on the task at hand may not be staring at the primary unit, so providing a multi-modal alert mechanism will improve worker responsiveness to the alert significantly.

For WZIAT to be effective, it must have the capacity to alert both workers and drivers. Providing an advance alert offers additional reaction time for the driver to adjust their actions, thereby preventing an

Table 7
WZIAT performance and operational features.

Alert system	Triggering mechanism	Operational capability
Integration of audio and visual alarms	Addition of a pneumatic tube for improved triggering in complex terrains	At least 24 h battery life and battery life indicator present
Alert unit should produce at least 100 dB 50 feet away from the alert source	Adjustable speed threshold options up to 65 MPH	Capability to incorporate multiple personal safety devices
Haptic/vibration alerts for workers wearing hearing protection	Control lateral triggering range for radar-based systems	Mobility for easy deployment and removal
Dual alert systems for both workers and drivers	Adjustable sensitivity of LiDAR	Waterproofing to facilitate year-round use
Customizable alert light colors		Reflective materials on devices for nighttime visibility
Oscillating or strobe-like visual alert perceptible at least 500ft from source		Limited need for external connecting technologies such as Bluetooth, Wi-Fi, GPS.
Alert control switch to manage expected work-related intrusions		Deploy in less than 3 min
Capability to incorporate multiple personal alert devices		

intrusion into the work zone. If the drivers fail to modify the behavior, the proactive nature of the device will provide workers with additional time to run to a safe place. Adding an option to control the color of light produced by the device would help the end-user adhere to different states restrictions regarding the use of lights in work zones. For instance, certain states prohibit the use of blue light in work zones (Ahmed et al., 2021). In addition to the color of light, the light intensity plays a critical role in perception (Gambatese et al., 2017). WZIATs should have Oscillating, flashing, or strobe-like lights that are perceptible at least 500 feet away from the light source. Given the need for work-related vehicles and equipment to enter the work zones at different times, it is important to have a feature that allows for remotely disarming the alert. A remote-control feature to turn the device on and off will help limit false positive alarms.

5.2. Triggering mechanism

The traffic control crew (including the flaggers and safety personnel) should collectively decide on the most appropriate location to deploy the WZIAT, especially in extended works zone closures where there could be multiple placement options. The additional features provided by some of the WZIATs – such as a pneumatic tube, additional alarm unit, and personal safety devices – should be taken into consideration as well. Adding a pneumatic tube to WZIATs as a trigger will help minimize the impact of directional or line-of sight-based triggering mechanisms. The pneumatic tube would ensure that work zones with elevated grades, curves, and intersections are better protected given the ability of the pneumatic tube to extend the triggering range of the primary unit. However, manufacturers should be mindful of potential radio frequency signal conflict that may arise when the system is deployed in a location that includes deploying other devices with similar frequencies.

When deploying WZIAT in work zones, workers should consider placing the device in such a way that it minimizes false positive as much as possible. Consistent false alarms will lead to alarm fatigue, thereby increasing the risk of workers ignoring alarms associated with intrusions. In work zones. Workers should be educated about the device triggering mechanism and how to avoid potential false alarms. WZIATs should include options for controlling (narrowing down) the lateral triggering range which would help when using the device in multi lanes highway. This option will significantly reduce the number of false positive alarms coming from lanes far from the work zone closed lane. The sensitivity of LiDAR should be adjustable to help reduce false alarms that could be generated from low-risk nonvehicle related intrusions.

For WZIATs that are triggered based on the speed thresholds designed to align with work zone speed limits, it is recommended that the options for the speed limit threshold account for potential work zones that do not impact the throughput speed (e.g., utility work conducted on the shoulder). A lower threshold will lead to multiple false positive alerts, which could impact both drivers and workers negatively. For instance, some work zones have a 65 MPH speed limit, and using a WZIAT that has an upper threshold of 45 MPH will generate constant false alarms. It is essential to develop mechanisms to control (narrow down) the lateral triggering range of radar based WZIATs. This limitation will help broaden the potential deployment application to include multi-lane highway work zones. Currently, radar based WZIATs would generate false positive alarms from multiple lanes (up to five) parallel to the closed work zone.

5.3. Operational capability

Operational guidelines for utilizing WZIATs in utility work zones most align with jurisdictional requirements, specifically those outlined in the Manual on Uniform Traffic Control Design (MUTCD) and state DOT guidelines. WZIATs should be integrated as an additional safety measure to enhance both driver and worker safety, not as a device that replaces existing traffic control devices. Although the use of WZIAT is expected to improve worker safety, there are some inherent risks associated with using it. Similar to most traffic control devices, workers are exposed to potential struck-by incidents when deploying and removing WZIATs. Therefore, workers should be mindful of the associated hazards when using WZIATs as part of their traffic control setup.

While the existing WZIATs are protected by a hard-shell case, the systems are not completely waterproof. WZIAT should be waterproof given that some utility work takes place during or after significant rainfalls. Having a water-resistant device will encourage contractors to adopt the technologies as they can use them throughout the year and not in only dry weather conditions, thereby improving the return on investment. Most of the current technologies have electronic components that are exposed to the elements, thereby making them sensitive to weather conditions such as rain. Additionally, it is essential for WZIAT system to have proactive battery management, including the availability of spare batteries, ensuring continuous device functionality, especially during extended utility operations exceeding a day. WZIATs should have battery level indicators on both the primary and secondary units. This will eliminate assumptions and guesses that could lead to a false negative (intrusion about to happen and the WZIAT system is not powered due to drained battery).

The mobility of WZIATs is an important adoption factor given the inherent characteristics of electric utility work zones (short term, short duration work zones). Contractors will have to deploy and remove these technologies often; therefore, manufacturers should ensure that WZIATs are easy to move around and deploy. Providing a compact system will facilitate adoption and diffusion. The setup and operation process for WZIAT should be as simple as possible. Preferably, manufacturers should limit the need for and reliance on additional technologies such as internet, Bluetooth, and software apps. Work zones may be located in remote areas that have poor cell phone coverage. Moreover, the use of advanced technologies places an extra burden on end-users who may not be familiar with these technologies.

6. Conclusions

The number of work zone intrusions continues to increase, leading to roadway worker injuries and fatalities, as well as damage to equipment and property. This problem is especially relevant to utility work zones, as their short work durations and setup locations provide an added challenge to traffic control, and thus, the need for further protection is evident. The combination of current traffic control methods, like signs and channelizing devices, with existing and emerging work zone intrusion technologies, could be beneficial in improving safety in work zones.

The present study identified critical risk factors associated with accidents in utility work zones. The study also identified several work zone intrusion technologies and evaluated their feasibility for utility work. The assessment led to the selection and evaluation of two technologies—AWARE and Alpha SafeNet. Live tests indicated positive perceptions among utility workers, especially in non-mobile operations. The study derived operational guidelines and a list of essential features for WZIATs in utility work zones based on insights generated from multiple sources. Overall, the research provides valuable insights and recommendations for enhancing safety in utility work zones through the deployment of effective WZIATs. It also identified WZIAT features which could be incorporated in future WZIAT design to reduce work zone intrusions in the utility industry.

However, this study had some limitations. Six companies and 21 individuals participated in the interviews, which could affect the generalizability of the results. The research team ensured representation from various types of companies in different geographical locations to limit potential bias. Future studies could improve generalizability by expanding the sample size. Additionally, the WZIATs was deployed on only one utility project, which may limit the generalizability of the findings. Future research should include a larger pool of test projects encompassing different types of activities and road geometries. This diversity could provide valuable insights into the effectiveness of WZIATs in the utility industry. Despite these limitations, the present study offers unique insights that can enhance both research and practice at the intersection of worker safety and utility operations.

CRediT authorship contribution statement

Abdallah Abdallah: Writing – original draft, Investigation, Formal analysis, Data curation. **Abdullahi Ibrahim:** Writing – original draft, Investigation, Data curation. **Chloe Russell-Vernon:** Writing – original draft, Methodology, Formal analysis, Data curation. **Chukwuma Nnaji:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **John Gambatese:** Writing – review & editing, Investigation, Conceptualization. **John Shober:** Writing – review & editing, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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