

IMPROVING WORK ZONE SAFETY WITH INTRUSION ALARMS



U.S. Department of Transportation



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IN THIS CASE STUDY YOU WILL LEARN:

1. What some emerging strategies that transportation agencies use in work zones are.
2. How work zone intrusion alarm (WZIA) technology helps enable work zone safety.
3. How Tennessee, California, and Oregon evaluated existing WZIA technologies and used their results to offer recommendations to other State DOTs.

Safety in Work Zones

Work zones present many challenges, both for drivers and road management: sudden stops, mandatory merging, and uneven road surfaces are a major cause of congestion, delays, and crashes [3]. Depending on severity, work zone crashes can accrue significant costs from associated fatalities, injuries, property damage, and operational disruptions. Despite the potential hazards, there is a growing need for work zone activities due to aging infrastructure as well as severe weather events.

Effective work zone management strategies and technologies are necessary to ensure motorist, construction, and maintenance worker safety, reduce congestion, and maintain access for work zone impact areas. The operational and safety benefits of effective work zone management are significant, especially in roadway networks with rapidly changing traffic conditions and along already-congested corridors.

In response to growing work zone safety concerns, transportation agencies across the country are using Intelligent Transportation Systems (ITS) to make traveling through and around work zones safer and more efficient. These technologies include portable variable speed limit systems (PVSL) [4, 5], automated flagger assistance devices (AFAD) [6], work zone intrusion alarms (WZIA) [7-9], virtual reality [10], internet of Things (IoT) and artificial intelligence (AI) [11, 12], and connected smart work zones [13-15]. Depending on the nature and constraints of a given work zone, different combinations of safety technologies can be used to improve overall safety. This case study introduces various emerging work zone technologies, with an emphasis on WZIA that detect intruding vehicles and alert workers. This case study also highlights safety outcomes, costs, and lessons learned from three states—Tennessee, California, and Oregon—that are early adopters of WZIA technologies.

The National Highway Traffic Safety Administration (NHTSA) and the Bureau of Labor Statistics (BLS) recorded 857 work zone fatalities and 117 worker fatalities in road construction sites in 2020 [1, 2]. The percent of highway worker fatalities involving workers on foot being struck by a vehicle increased by 9.6 percentage points from 2019 to 2020. While work zone statistics in 2021 are not available yet, early estimates of total traffic fatalities in 2021 show an increase of about 10.5 percent as compared to reported fatalities in 2020 [1].

Leveraging Technology to Improve Work Zone Safety

ITS deployment for work zone management can take many forms. Common technology applications include real-time traveler information, queue warning, dynamic lane merge, incident management, variable speed limits (VSL), automated enforcement, entering/exiting construction vehicle notification, and performance measurement [16]. Several new technologies have been tested recently by transportation agencies and researchers for a range of purposes. Some were deployed in the field to improve work zone safety, while others were used to improve operations on the back-end to validate work zone events, reduce emergency response times, or test new prototype work zone solutions. These technologies are summarized as follows.



Figure 1. AFAD and CMS Signs *Source: MoDOT.*

Work Zone Intrusion Alarms (WZIA) – A WZIA system is a set of equipment that is intended to recognize when a work zone intrusion is occurring, and provide audible, visual, or vibratory alarms to rapidly alert drivers and field workers of the intrusion. According to some early adopters of WZIA technologies [7-9], WZIA systems have been found to be a cost-effective intervention to improve work zone safety.

Portable Variable Speed Limit (PVSL) – PVSL signs, often paired with traffic sensors that detect traffic flow and speed information, provide real-time and dynamic speed limit notifications to motorists. Studies from Utah and Texas showed that deployment of PVSL successfully reduced average freeway speeds by 15 to 25 miles per hour (mph) and reduced the number and severity of crashes near work zones [4, 5].

Automated Flagger Assistance Devices (AFAD) – AFADs are automatic traffic control devices that replace human flaggers to direct traffic at lane closures. An AFAD system implemented by the Missouri Department of Transportation (MoDOT) (Figure 1) induced slower vehicle approach speeds (4.2 mph slower on average), shorter waiting times (33 seconds shorter on average), quicker traffic release (1.28 seconds quicker on average) and successfully stopped vehicles farther back (11.4 feet on average) than human flaggers [6].

Internet of Things (IoT) and Artificial Intelligence (AI) – IoT and AI are also trending technologies for smart work zone systems. For example, computer vision technologies have been used to develop video-based traffic measurement systems for work zone queue detection [11]. AI approaches can facilitate faster validation and reduce emergency response times through analysis and reporting of real-time crash locations from a variety of data sources—including in-vehicle navigation devices, roadside traffic detectors, and crowdsourced mobile applications—to enable detection of significantly more traffic crashes [12].

Virtual Reality (VR) – VR environments are virtual representations of real-world settings and have proven to be a suitable alternative for field experiments, generating a “real” sense of being in a work zone while providing a safe, simulated alternative for performing human behavior studies. For

example, a research study that combines microscopic traffic simulation around work zones with a realistic VR implementation is being used to test solutions to alert field workers to vehicles [10].

Connected Smart Work Zones – Several State DOTs, such as the Wyoming and Minnesota DOTs, have assessed the effectiveness of connected and automated vehicle (CAV) work zone warnings to improve work zone safety [13-15]. Although further testing is needed, a preliminary Wyoming DOT driving simulator experiment revealed that traveler information messages increased the mean time-to-collision by 40 percent, which potentially provides the driver with more time to avoid a crash, and decreased the mean deceleration time to avoid a crash by 19.3 percent [14].

WZIA Technologies

Maintaining worker safety in work zones is of paramount concern to highway agencies. One way to reduce work zone crashes is to use a WZIA system to alert drivers and workers when a work zone intrusion occurs so they can respond appropriately. Typically, WZIA systems use wireless sensing technology, mechanical impact sensors, or pressure sensors and consist of a detector, transmitter, and auditory alert device. Some WZIA systems have additional components, such as personal safety devices (PSDs).

The first WZIA system in the U.S. was developed under the Strategic Highway Research Program (SHRP) with ultrasonic and infrared beams used for detection [17]. Since then, other intrusion alarms have been developed using technologies such as microwave, pressure activated sensors, and laser beam.

Based on the nature and type of detection, currently available WZIA technology systems can be broadly divided into six categories [8]: 1) kinematic, 2) infrared-based, 3) pneumatic, 4) microwave, 5) radar-based, and 6) radio-based. Technologies based on impact detection (e.g., kinematic and pneumatic intrusion technology systems) typically use barrier mounted or pneumatic sensors to detect intruding vehicles, while wireless sensing technologies use wireless signals, such as infrared or microwave, for detection. The alert mechanism of a WZIA system usually includes audible, visual, and vibratory alerts.

Evaluating and Field-Testing WZIA Technologies

Several WZIA technologies have been developed by manufacturers and evaluated by DOTs and researchers (Figure 2). In 2018 researchers evaluated the effectiveness of multiple WZIA systems via pilot testing in California and assessed their readiness for deployment in work zones [8]. The testing consisted of a trip hose used for vehicle detection, an alarm unit attached to the vehicle, and PSDs for work zone workers. In this pilot, data were collected to evaluate sound level, operation, functional characteristics (e.g., transmission range, false alarm rate), and worker reaction time. The kinematic and radio-based system has a motion-sensitive cone lamp and web-enabled alarm unit, and the pneumatic and microwave-based system has an auditory, visual, and haptic alarm that is wirelessly triggered when it detects an intruding vehicle over a positioned pneumatic hose. The findings revealed that implementation of these two WZIA systems in California work zones could provide additional safety benefits, supplementing existing safety practices for the benefit of work zone workers and reducing work zone fatalities. A third WZIA technology with a

disposable CO2 cartridge to operate an air horn alarm was also tested. However, it was not implemented further due to installation challenges (e.g., difficulty in screwing-in and replacing the CO2 cartridges), transport challenges (e.g., space limitations in the trucks), and performance issues (e.g., inconsistent air horn performance from freezing and moisture accumulation).

A Tennessee study [7] evaluated three existing WZIA technologies: 1) an impact-activated system that utilizes traffic cone mountable sensors and Portable Site Alarms (PSA), 2) a radar-based warning system that marks a vehicle as an intruder if it is traveling at a speed higher than the speed limit, and 3) a pneumatic sensor-based technology with a pneumatic trip hose sensor, signal transmitter, Portable Alarm Case (PAC), LEDs, and PSDs. Live test results in 2019 and 2020 found that overall, all three WZIA systems were user-friendly, easy to install and use, and durable. The radar-based warning system was the most durable and the least likely to raise false alarms. WZIA technologies using cone mountable sensor lamps were found to be best suited for long-term stationary work zones among the three systems tested due to their good coverage and cost.

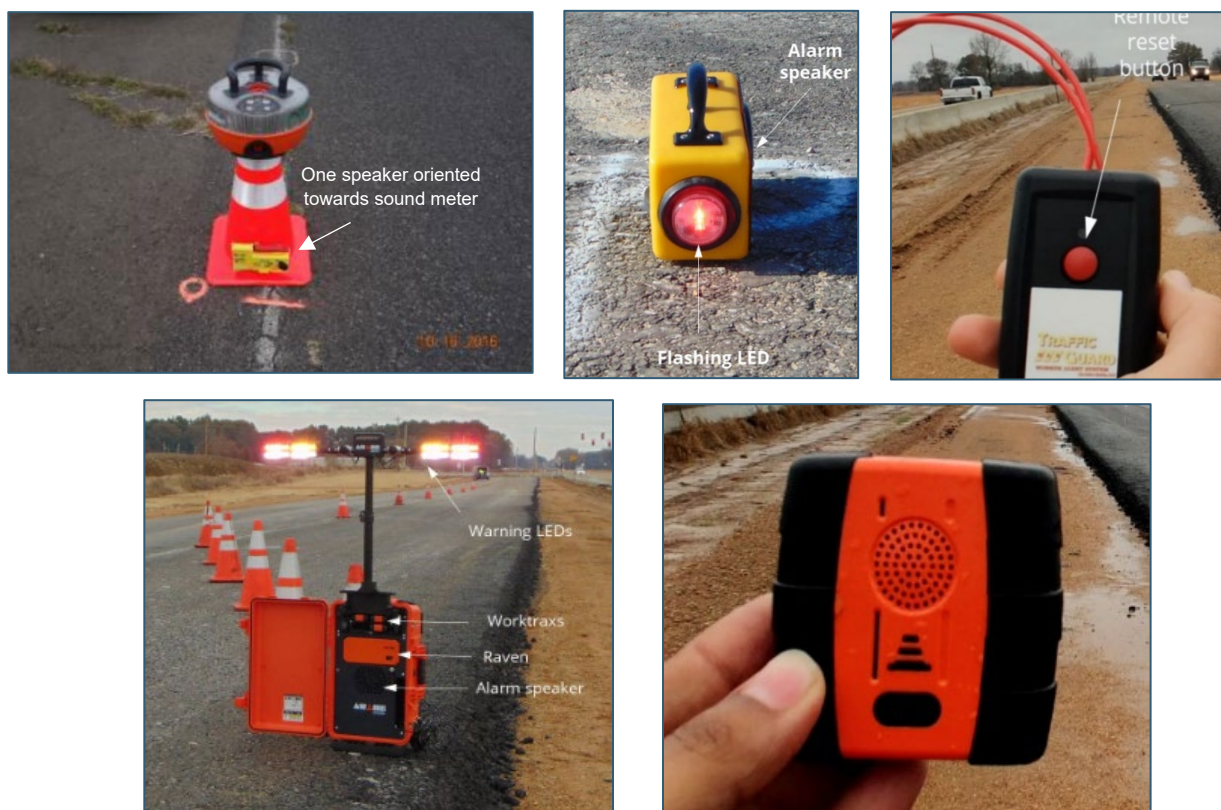


Figure 2. Various WZIA Technologies Source: ODOT and TDOT.

Research efforts by the Oregon DOT and Oregon State University (OSU) evaluated three commercially available WZIA technologies using impact-tilt, wireless sensor-based, and pneumatic sensor-based alarm systems under controlled conditions in active work zones [9]. The findings from these three WZIA technologies showed that intrusion alarms via visual, audio, and haptic means can be effective warning mechanisms in a work zone, but the level of effectiveness varied depending on various factors, such as the position of the devices, the mechanism used to trigger the alarms, and the hearing abilities of the workers. Testers indicated that the alarm accuracy was the most important criteria followed by the triggering mechanism accuracy.

Deployment Cost Estimates

As WZIA technologies are still evolving, the cost to deploy them varies depending on the system selected, level of coverage, and the safety features offered by each system. It is important to note that some emerging WZIA systems may only be available outside the United States, requiring procurement mechanisms to be carefully identified. The estimated costs¹ to deploy and/or maintain a WZIA system from the three examples are presented in Figure 3. In addition to the capital costs, agencies must also budget for costs associated with equipment installation and mobilization, training, and software/hardware configuration.

California: The capital costs (excluding labor costs) of the WZIA systems evaluated in California range from \$4,630 to \$11,100 based on a hypothetical half-mile closure on a two-lane road.	Oregon: A pilot test of three commercially available WZIA systems found capital costs can range from \$1,260 to \$5,940 based on a one-mile single lane work zone closure.	Tennessee: The estimated cost to deploy and maintain a WZIA system can range from \$6,600 to \$31,028 per year depending on the type of technology and the number of sensors for a hypothetical work zone 1,000 feet long on a highway.
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*Figure 3. Estimated Costs of the WZIA Technologies Evaluated in the Three Examples.
Source: Caltrans, ODOT, and TDOT.*

Lessons Learned for Different Types of WZIA Systems

Some key lessons learned regarding different WZIA systems are summarized below. It is worth noting that these are based on the examples from California [8], Tennessee [7], and Oregon [9], and further evaluation will be needed if different safety features from those tested in these example WZIA systems are used.

- **WZIA system using cone mountable sensors and PSA:** Since this type of WZIA system is best suited for lane closures longer than 1,000 feet and maintained for several days with an unlimited transmission range, it is suggested for deployment in work zones on major highways. This type of WZIA system provides good work zone coverage, distinct and loud alerts, and a low life cycle cost; however, setup can be time-consuming. Potential false positives and negatives and issues with connectivity should be taken into consideration.
- **Radar-based WZIA system:** This type of WZIA system has good work zone coverage, distinct and loud alerts, accurate intrusion detection, and a quick setup. It is suggested for use on short-term work zones where it can be removed and stored safely after completion of work.

¹ The costs presented in Figure 3 are based on different assumptions and thus are not fully comparable. For detailed information on the costs, please refer to the corresponding State reports [7] [8] and [9].

- **Pneumatic sensor based WZIA system:** This type of WZIA system has multiple alert sounds, a low life cycle cost, and a quick and easy setup. However, transmission lags reduce usefulness for workers close to traffic. It is ideal for use in short-term work zones that are not too close to the traffic (e.g., short-term repair projects on highway shoulders and mobile work zones). In addition, providing a high-power repeater unit or incorporating a hook or collar in the pressure sensor can improve reliable signal transmission range.

Lessons Learned for Specifications

The three examples [7-9] revealed certain minimum specifications for technology deployment to significantly improve the usefulness of the technologies in practice. These are highlighted below.

- **Sound level and type:** The sound alarm produced by the WZIA technology should be at least 110 decibels when the alarm is located 50 feet away from workers, and above 95 decibels when the alarm is 100 feet away. Sound types that significantly differ from the noises heard during the operation (e.g., diesel engine noise from equipment, passing cars) are preferred to improve sound distinction.
- **Transmission distance:** Factors such as expected vehicle travel speed and time required for a worker to dodge an intrusion are crucial when determining adequate transmission distance. The minimum transmission distance is suggested to be 400 feet when the work zone speed is about 35 mph, assuming a 6-second reaction time for a worker who is 100 feet behind (or in front of) the construction and maintenance operations.
- **Haptic and visual alarms:** The alert light is recommended to be visible 500 feet away, as visual alerts are an extremely important part of WZIA technologies. Adding haptic feedback offers an additional type of warning which can help overcome issues related to a masked alarm sound (due to heavy equipment noise) or blocked line of sight.
- **Mobility and ease of use:** Ease of use plays an important role in selection and implementation decisions for WZIA technologies. Workers prefer an intrusion alert technology that is easy to set up, deployed at the beginning of a shift, and retrieved at the end of a shift with limited exposure to traffic.
- **Triggering mechanism:** Radar- or sensor-based work zone coverage that is independent of the roadway infrastructure or traffic control devices—or other, non-impact-dependent intrusion alert systems—is recommended if the triggering mechanism's accuracy is especially important to agencies (e.g., few false alarms).

References

Where possible, a link to the summary of the source contained in the ITS Databases is included. You can visit the ITS Deployment Evaluation Benefits, Costs, and Lessons Learned Databases at: www.itsknowledgeresources.its.dot.gov

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