RESEARCH & DEVELOPMENT

TT2019-24 -Work Zone Intrusion Alert System Technology Tests

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Work Zone Intrusion Alert System Technology Tests

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16. Abstract

This study will evaluate the effectiveness of the work zone intrusion detection and alert system prototype that was developed by Dr. Erol Ozan. The project team tested the system at selected actual work sites and at a closed track facility in North Carolina. The project employed a number of data collection and scientific observation methods to test the applicability of the technological approach in the field including the following: (1) safe intrusion experiments to measure the effectiveness of the intrusion detection and timely activation and the dissemination of the alerts; (2) the observation of the device performance at actual work areas; (3) conducting a survey to capture opinions of the study participants in various aspects of the system (user-friendliness, ease of setup, performance, compatibility with the work zone environment).

17. Key Words *Smart work zone, artificial intelligence, Internet of things, work zone intrusion alert, vehicle intrusion detection*	**18. Distribution Statement**

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Executive Summary

This study explores the feasibility of camera-based work zone intrusion detection and alert technology through testing a prototype system at selected work sites and a training facility. The prototype system uses an Android smartphone to capture and process the video feed. When an intrusion event is detected, the smartphone generates audio alarms on a portable speaker and triggers alarms (both audio and vibration) on personal smartphones carried by workers. The prototype was tested during four test sessions that took place at different locations. One session took place in a closed training track facility while three sessions were conducted at actual work zones in active roadways. A survey questionnaire was administered at the conclusion of the test sessions. The survey instrument captured potential users' opinions and perspectives about the useability of the prototype at actual work zones.

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1. Introduction

This project partially builds on the findings of an NCDOT-sponsored project (RP#2019-24 "Using IoT to Create Smart Work Zones") that developed a proof-of-concept work zone intrusion detection and alert system (Ozan, 2020). RP#2019-24 ended in July 2020 and since then the author transformed the proof-of-concept system into a prototype. The objective of this project is to test the prototype and observe its performance at the work sites and testing facilities designated by the NCDOT. This study addresses the work zone safety problem by evaluating a new visible spectrum camera-based vehicle intrusion detection and alert technology. The design is based on AI, computer vision, and IoT technologies. At the time of writing of this report, no camera-based work zone intrusion alert product existed at the marketplace to the best of the knowledge of the author. The existing work zone intrusion detection systems are discussed in the papers written by Awolusi & Marks (2019), Gambatese, Lee, & Nnaji (2017), Jacobs (2018), and Nnaji, Gambatese, & Lee (2018).

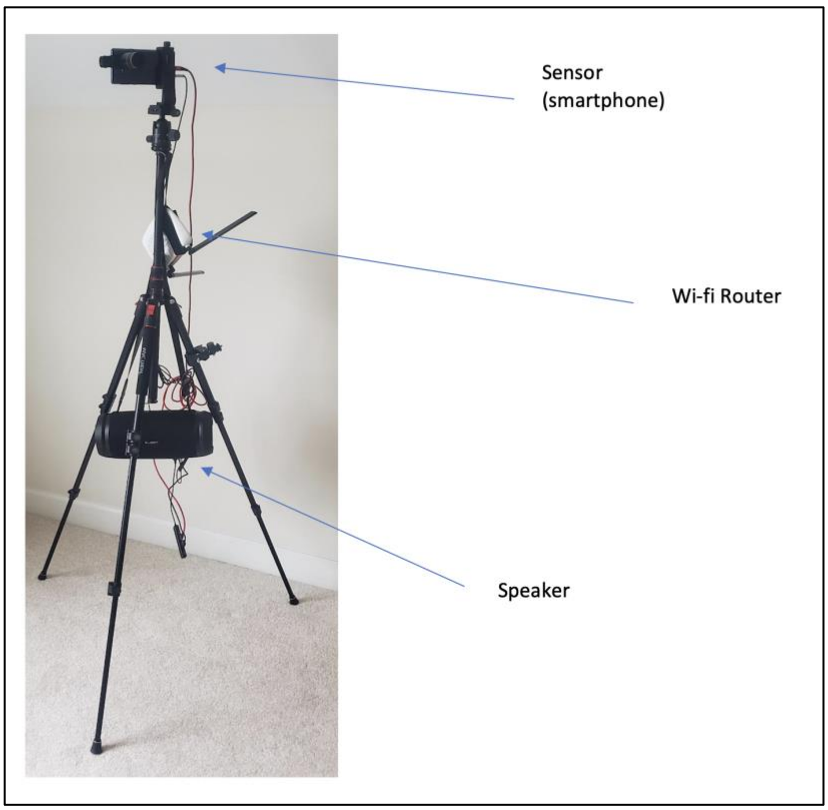
This project focuses on the following research objectives:

- Test and observe the performance of the prototype at actual work zone sites
- Test the intrusion detection accuracy and the timeliness of alerts by conducting safe intrusion experiments. Safe intrusion tests involve a team member driving a vehicle through the restricted area while the second team member observe and record the activity and response times of the prototype
- Obtain workers', supervisors’, and field engineers' opinions on the system's effectiveness and performance.
- Determine the strengths and weaknesses of the camera-based intrusion detection technology

At the completion of the project, one fully functional prototype unit and a user manual were turned over to NCDOT. The prototype unit included all the necessary components to operate one functional unit.

2. Description of the Prototype Work Zone Intrusion Alert System

This chapter describes the prototype system developed by the author and that was tested in this project. The prototype is a portable battery-powered system that detects intrusion events in the selected parts of the work zone and generates audible alarms when intrusion incidents occur. The system also relays alerts to smartphone devices worn by the workers to augment the alarm effectiveness. The prototype's image and the main components are shown in Fig. 1. The components of the system are mounted on a tripod and a portable alert receiver was also included in the tests. The technical characteristics of the prototype are summarized in Table 1.



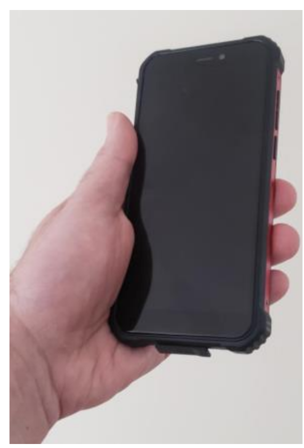


Figure 1 Prototype system and the personal alert device

Table 1 Technical Characteristics (detector unit with standard tripod-based mount)

Height:	5 feet – 7 feet. (Adjustable height)
Width:	34 inches
Weight:	11.5 lbs.
Power:	Battery powered

In this study, the tests focused on the placement of the sensor between the end of the buffer space and the beginning of the active work area. Fig. 2 depicts the setup employed in this study, which involves the camera placement closer to the active work area while camera pointed towards approaching traffic.

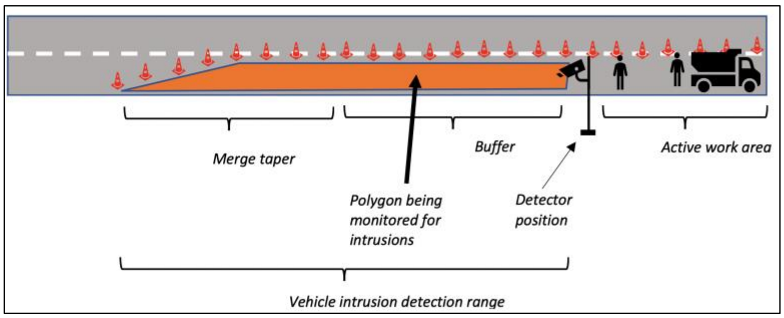


Figure 2 Detector position and detection area in a work zone

The prototype's intrusion detection function relies on image-based vehicle detection capability. To ensure a robust detection, the sensor should be mounted on a stable platform. The next step is to designate the area that will be monitored. The device operator identifies the area that will be monitored by drawing a polygon on the device screen. Once the polygon is created, the device becomes ready to monitor the selected area to detect entry of a vehicle into the restricted area. The prototype system uses a smartphone as a sensor and a signal processor. The application that runs on the smartphone constantly monitors the restricted area. If the system detects a vehicle in the designated polygon area, the application activates a general alarm and invokes alerts (audio and vibration-based) on the mobile devices worn by the workers. The test system uses the Wi-Fi data connection at the work site to relay the alerts in the work zone. The detailed explanation of the intrusion detection and alert generation algorithms and methods can be found in the NCDOT RP#2019-24 project report (Ozan, 2020).

3. Field Tests

This study employed two types of test settings. The first one was conducted at a training track closed to public traffic. The second type took place at the actual work sites with one lane closures on two-lane roadways with active traffic. The following sections describe the findings of those test sessions.

3.1. Safe Intrusions Experiments at TIM Training and Development Track

The project team conducted safe intrusion experiments at TIM Training and Development Track that is located on 380 East Tryon Road in Raleigh, North Carolina (Fig. 3) (Ozan, 2020). The facility contains a set of roadways that are isolated from the public traffic. For the purposes of this research report, a safe intrusion experiment is defined as emulation of work zone intrusion incidences in a safe and controlled environment. In such a setting, a simulated intrusion event is created by using a vehicle driven by a crew member, enabling researchers to observe the safety device's reaction under different parameters and scenarios.

Figure 3 Tests at TIM Training and Development Track

Table 2 Distance to sensor vs. Detection Time

Distance to Intrusion Point (m)	Detection Delay (msec)
30.43	390
41	320
44.4	460
58.33	320
58.33	580
63.63	660
68.18	1020
81.8	1040
100	1100
100	1040
150	1430
150	2680
150	3010

The experiments were conducted between 9 AM and 12 PM on November 4, 2021. The weather condition was mostly cloudy with intermittent light rain. Wind and temperature were reported as NE 8 mph and 48/45 F respectively. For the safe intrusion experiments, a work zone was setup. The work zone featured one lane closure on a two-lane roadway. During tests two lengths of road closures were employed: 100 m and 150 m. Intrusion events were simulated with a vehicle travelling at various speeds, ranging between 35 mph and 70 mph, and entering the closed off area at various distances from the sensor. Table 2 shows the detection delays versus distance of the intrusion entry point into the restricted area and the camera. The delays ranged between 320 ms and 3,010 ms. The results showed that for the distances that are longer than 60 m, the device produced long delays. Careful analysis of the findings indicated that the algorithm cannot detect vehicles unless they occupy roughly around 30% of the vertical length of the frame. Therefore, to reduce the delays to acceptable levels, optimal amount of digital and/or optical zooming must be applied. That ensures sufficiently large images of the intruding vehicles can be captured by the camera. Significant delays in alerts generated on personal devices were observed. Those delays ranged between 1.5 seconds to 2.6 seconds. Analysis of the software code that generates personal device alerts indicated that the delay could be reduced significantly by algorithmic improvements.

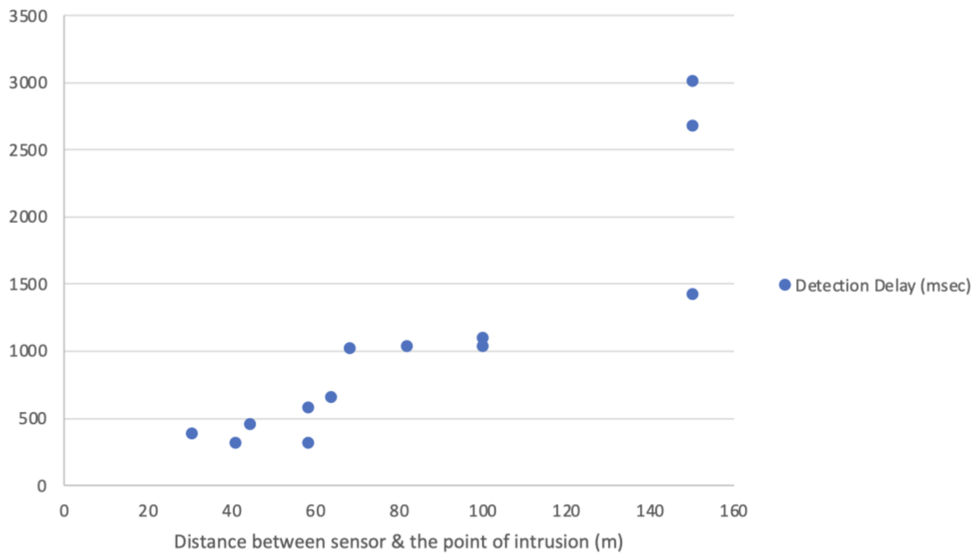


Figure 4 Detection Delay vs. Distance from the Intrusion Incident

At the conclusion of the session, a survey questionnaire (see Appendix for the survey instrument) was administered to eight individuals who observed the working of the prototype. The results are shown in Tables 3 and 4.

Table 3 Job titles of the participants

	Safety	Engineer	1 H	Safety Officer
Job title	4	2	1	1

Table 4 Previous experience of the participants in using work zone intrusion alert systems

	no	yes
Previous experience	5	3

Table 5 Survey results captured at work zones (Questions 2 thru 10 and Question 12)

Scores → *Brief Description of the question:*	**1**	**2**	**3**	**4**	**5**	Average Score
Q2. Training requirements			4	1	2	3.71
Q3. Time to setup	1			5	2	3.87
Q4. Easiness of use			5	2	1	3.5
Q5. Required effort to operate		3	2	1	1	3
Q6. Audibility of general Alarms		4	4			2.5
Q7. Audibility of personal alarms	1	2	1			2
Q8. Noticeability of vibration-based alerts	2	1	1			1.75
Q9.Usability of the personal alert devices		4	3			2.43
Q10. Effectiveness of intrusion detection (skipped if no intrusion event occurred)		3	2	1		2.66
Q12. Overall effectiveness of the system	3	1	3	1		2.25

The participants' responses to Questions from 2 to 12 are reported in Table 5. They indicate that the survey participants find the prototype relatively easy to setup and use. They also rated the training requirements as an average score of 3.71, indicating the training requirements are found to be minimal or low. The required effort level for operating the equipment received an average of 3, which indicates an acceptable level of effort for a device such as this. Intrusion detection effectiveness received an average score of 2.66. Overall effectiveness of the system was rated 2.25 in average.

The survey participants indicated their opinions on the potential use cases for the prototype by checking the boxes for each setting type (see Table 6). Long-term stationary project type was found to be potential use case by 6 out of 8 participants. At least half of the survey participants agreed that the prototype can be used for all range of project durations. As for the work setting type, 6 participants indicated that rural, low-speed, and low-traffic settings can be suitable for this technology. High speed and urban settings were selected by the least number of participants. The participants' evaluations were roughly equal for all natures of work.

Table 6 Evaluation of the potential use cases (Question 11)

Nature of work:		**Work Setting**		**Duration of Work**	
Roadway Pavement	5	Urban	3	Long-Term Stationary	6
Utility repair/maintenance	6	Rural	6	Intermediate-Term Stationary	4
Roadway widening/construction	5	Low speed	6	Short-Term Stationary	5
Intersection signalization	5	Intermediate speed	4	Short Duration (work that occupies a location up to 1 hour)	4
		High Speed	3	Continuously Moving Mobile Operations	4
		Low traffic volume	6	Intermittent Mobile Operations	4
		Average traffic volume	4		
		High traffic volume	3		

3.3. Results of the Tests Conducted at Actual Work Zones

This section reports the findings of the tests that were conducted at actual work zones. The field tests were conducted during three distinct days at three different locations. The main characteristics of each test site are shown in Table 7. All sites featured one lane closure on two-lane roadways. During Test #1, there was no active work being conducted at the site. Test #2 and #3 involved a moving maintenance work.

Table 7 Characteristics of the Test Sites

Test#	Location	Date/Time	Brief Description of the Site
1	US-301 Near Wilson County, NC	9:45 AM - 11:30 AM on 5/5/2022	One lane closure on 2-lane roadway. Type of Work: Non-active Work Zone
2	US-64, Nashville, NC	9:30 AM – 12:00 PM on 5/16/2022	One lane closure on 2-lane roadway. Type of work: leveling roadside ground
3	US-64, Rocky Mount, NC	9:30 AM - 12:00 PM on 5/17/2022	One lane closure on 2-lane roadway. Type of work: roadside tree trimming

During the test sessions, the author explained and demonstrated the use of the prototype to the available work crew. At the conclusion of the tests, the survey questionnaire was filled out by the crew members who had an opportunity to observe the device. The main findings of the survey data are as follows. Only one survey participant responded as having a supervisory role in work sites. None of the survey participants have had previous experience with work zone intrusion alert devices in the past.

Table 8 Job titles of the participants

	Other	Supervisor
Job title (supervisor or not)	5	1

Table 9 Previous experience of the participants in using work zone intrusion alert systems

	no	yes
Previous experience	6	0

Among all the questions that addressed the various attributes of the prototype, the time to setup received the most favorable score with an average of 4.66. Training requirements, easiness of use, and effort required to operate the device also received favorable ratings with average scores above 3. The audibility and noticeability of both general and personal alerts were rated unfavorably by the participants. During the tests, there were no intrusions, so it was not possible to observe the reaction of the prototype when an actual intrusion occurred. The survey participants rated the overall effectiveness of the system as 3.

Table 10 Survey results captured at work zones (Questions 2 thru 10 and Question 12)

Scores → *Brief Description of the question:*	**1**	**2**	**3**	**4**	**5**	Average Score
Q2.Training requirements	1		3		2	3.33
Q3.Time to setup			1		5	4.66
Q4.Easiness of use		1		5		3.66
Q5.Required effort to operate		1	2	2	1	3.5
Q6.Audibility of general Alarms	2	3	1			1.83
Q7.Audibility of personal alarms	3	1	2			1.83
Q8.Noticeability of vibration-based alerts	2	1	1			1.75
Q9.Usability of the personal alert devices	4		1	1		1.83
Q10.Effectiveness of intrusion detection (skipped if no intrusion event occurred)	1					1
Q12.Overall effectiveness of the system		1	3	1		3

Survey participants also evaluated the feasibility of using the prototype system in various work zone project settings. Long-term stationary projects were rated as the most suitable type of project for the technology. High-speed roadways were also rated as potentially suitable use case for the device. Continuously moving mobile work projects were not selected by any of the survey participants. The results indicate that most participants think that this technology may be useful in long-term stationary projects that are on high-speed roadways. Half of the responses indicated roadway pavement as a suitable type of work for this type of an alert system.

Table 11 Evaluation of the potential use cases (Question 11)

Nature of work:		**Work Setting**		**Duration of Work**	
Roadway Pavement	3	Urban	2	Long-Term Stationary	6
Utility repair/maintenance	2	Rural	2	Intermediate-Term Stationary	3
Roadway widening/construction	2	Low speed	1	Short-Term Stationary	1
Intersection signalization	1	Intermediate speed	1	Short Duration (work that occupies a location up to 1 hour)	2
		High Speed	5	Continuously Moving Mobile Operations	
		Low traffic volume	3	Intermittent Mobile Operations	1
		Average traffic volume	3		
		High traffic volume	5		

During the tests, the author recorded qualitative observations regarding the following:

- Ease of establishing an effective area to be monitored
- Effectiveness of various sensor mounts

- False alarms (potential triggers)

It is not feasible to observe the frequency of missed alarms through actual work site tests since intrusion incidents are relatively rare events. The following provides a summary of the qualitative observations recorded during the tests conducted at work zones. The most critical aspect of the work site is whether the roadway and its surrounding are conducive to establish a camera position where a direct line of sight can be obtained to monitor the target area. During Field Test 2 and Field Test 3, that turned out to be challenging since the camera view of the target segments within the closed-off road segment was obstructed by trees and by work vehicles. This issue is likely to be the case in many work sites. The solution to this problem is to position the camera further away from the active work area, closer to the target monitoring area. However, that solution would require a reliable and effective wireless data connection between the sensor and the alarm unit since alarm should be close enough to workers to ensure audibility. Alternatively, a high-power siren can be used to alert the workers. During the tests, three different camera mounts were employed: a regular tripod; a 20’ tripod stand; and a magnet mount. The advantages and disadvantages of each mount type are summarized in Table 12.

Figure 5 20’ tripod stand mount and controlling the sensor via a tablet device

Table 12 Comparison of Different Camera Mounts

Camera Mount Type:	**Advantages**	**Disadvantages**
Regular tripod (5 – 7 ft high)	Suitable to many use cases. Familiar and easy setup.	Limited height, needs to be re-setup if work zone moves
20’ tripod stand	Provides better camera angles. Can monitor further distances.	Needs to be re-setup if work zone moves. Longer setup times. Can be susceptible to strong winds. Necessitates a secondary device to control the sensor.
Magnet based mount	Can endure strong winds. Small unit. Easy to place and remove.	In most cases, necessitates a secondary device to control the sensor.

Magnet based mount proved to be very practical to use. It provided a stable platform, and it was found to be more resistant to winds than tripods. When the magnet was attached on a truck’s roof, a secondary device (a tablet) was used to control the camera and setup the polygon. The data connection between the secondary device and the main camera unit worked effectively and allowed the operation of the device from about 20 m maximum. In a moving work project, a magnet mount has benefits. It would not require the setup of the tripod every time crew moves. The camera unit can be mounted on a work vehicle, and it would be moved with other equipment without requiring additional efforts to moving and adjusting the tripod. Fig. 6 and Fig. 7 show two different placement of the magnet mounted sensor: on crash attenuator and a truck.

Figure 6 Mounting the sensor on crash attenuator

Figure 7 Mounting the sensor on work vehicles

Field tests were instrumental in identifying the conditions that trigger false alarms. A typical case where a false alarm is generated is illustrated in Fig. 8. False alarms are possible in the following typical condition. The vehicle detection algorithm of the prototype identifies a rectangular box that encloses the detected vehicle (shown with the red colored rectangle) in the image. In Fig. 8, the blue lines indicate the polygon area that is monitored by the prototype. In the case presented in Fig. 8, an alert is generated because the rectangle area intersects with the polygon area, although the vehicle does not intrude the restricted area. These types of false alarms are more prominent when the camera target close by vehicles and usually the roadway angled less than 45 degrees as illustrated in the Fig. 8. Recommended usage is to target the roadway portions typically located more than 50 meters away from the sensor, which should alleviate the issue.

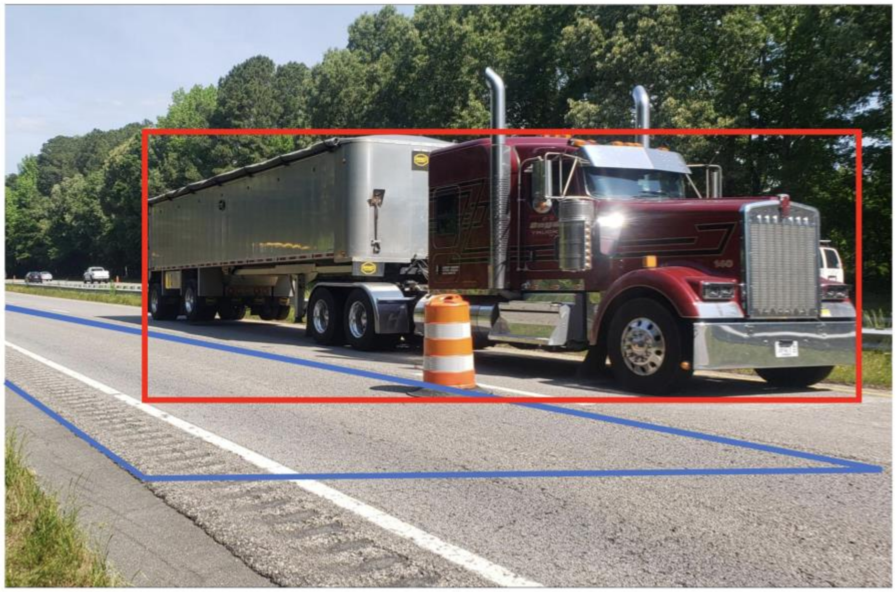


Figure 8 Illustration of a condition triggering a false alarm

3.4. Combined Results

This section reports the combined results gathered from all test sites. Four attributes received a score greater than 3. They represent the following area: training requirements, time to setup; easiness of use, and required effort level to operate. Five attributes were below the score of 2.5, mid-point of the rating scale: audibility of general alarms, audibility of personal alarms, noticeability of vibration alerts, intrusion detection effectiveness, and useability of personal alerts. Intrusion effectiveness rated as 2.42, indicating delays in alert generation. Overall effectiveness received an average score of 2.53 indicating the system needs modifications to be deployed in the field. Only 3 participants had previous experience with similar safety systems in the past.

Table 13 Previous experience of the participants in using work zone intrusion alert systems

	no	yes
Previous experience with WZ alert systems	11	3

Table 14 Combined survey results captured at work zones (Questions 2 thru 10 and Question 12)

Brief Description of the question:	**Average Score (1 to 5 scale)**
Q2. Training requirements	3.53
Q3. Time to setup	4.21
Q4. Easiness of use	3.57
Q5. Required effort to operate	3.23
Q6. Audibility of general Alarms	2.21
Q7. Audibility of personal alarms	1.9
Q8. Noticeability of the vibration-based alerts	1.75
Q9. Usability of the personal alert devices	2.15
Q10. Effectiveness of intrusion detection (skipped if no intrusion event occurred)	2.42
Q12. Overall effectiveness of the system	2.53

Long-term stationary projects were found to be the most suitable use case for the technology. Mobile operations were rated as least suitable for the use of the prototype. A breakdown of the utility of the prototype in various use cases is provided in Table 15.

Table 15 Evaluation of the potential use cases (Question 11)

Nature of work:		**Work Setting**		**Duration of Work**	
Roadway Pavement	8	Urban	5	Long-Term Stationary	12
Utility repair/maintenance	8	Rural	8	Intermediate-Term Stationary	7
Roadway widening/construction	7	Low speed	7	Short-Term Stationary	6

Intersection signalization	6	Intermediate speed	5	Short Duration (work that occupies a location up to 1 hour)	6
		High Speed	8	Continuously Moving Mobile Operations	4
		Low traffic volume	9	Intermittent Mobile Operations	5
		Average traffic volume	7		
		High traffic volume	8		

Table 16 Comments provided by the survey participants (Question 13)

Comments:
"Time delay, distance travelled."
"With noise from traffic, equipment trucks and other it would require something like a train horn or device for each person to carry on [themselves] but what about the cost? I know it could save lives, but all of us don't have computer skills, but want to learn."
"Alert could be louder."
"Continue to test."

Table 16 provides the comments that the four participants provided. Two of them indicated a need for louder alarms. One pointed out the issue of the delay observed with the alarm generation. Importance of additional tests was emphasized by one of the participants.

4. Discussion of the Results and Conclusion

The results of this study indicate that the use of camera-based intrusion detection and alert technology provides potential to become a feasible solution for work zone intrusion detection. Further product development can extend the potential use cases and effectiveness of the technology. The technology is generally found to be easy to deploy and operate. The alarm generation and intrusion detection functions need further improvements to be viable in a typical use case.

In this project, we were not able to demonstrate a stable performance for the personal alert devices. The results indicate that a more robust wireless data connectivity is needed at work zones. The specific solution used in the prototype system, was to use a portable wireless router to handle the data connection between the sensor and the personal alert units. However, it has been determined that more work and testing need to be done to ensure a reliable data coverage. We did not consider the use of cellular data network for data transmission since project scope indicated a need for data transmission without an Internet connectivity at work sites.

This study determined that different camera mounts can extend the usability of the technology providing benefits in user-friendliness and resolving the issues of obstructed camera view. Sound levels of audio alarms must be optimized to be heard by the workers. The prototype used a portable speaker for generating alarms, however, the loudness was rated as inadequate by many participants. This is relatively easy problem to address in future iterations of the technical solution.

The technology is found to have optimal applicability in long-term stationary projects. This study concludes that the camera-based intrusion detection and alert systems have potential to become feasible safety systems as the technology matures. It is very likely that future smart work zones will employ a version of the technology demonstrated in this study.

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Appendix: Survey Questionnaire

Evaluation of a Work Zone Intrusion Detection and Alert System

Describe Survey Participant's Role/Job Title/Responsibility:__________________________________

1. Have you had any experience in operating or evaluating other work zone intrusion detection and alert systems in the past?

_____Yes, please specify the products you have used:

…………………………………………………………………………

_____No

2. Please select the best option that describes the required level of training to operate the equipment:

1	2	3	4	5
Required training is overwhelming and infeasible for an average user	Required training is difficult for an average user	Required training is substantial but acceptable for an average user	Required training is medium level for an average user	Required training is minimal for an average user

3. How long does it take to setup the equipment? (Select the best option below)

1	2	3	4	5
Longer than 1.5 hrs.	61 min to 1 .5 hrs.	41 – 60 min.	21 - 40 min.	0 – 20 min.

4. Is the system easy to use?

1	2	3	4	5

Extremely difficult to use	Difficult to use	Average	Easy to use	Very easy to use

5. Please select the best option that describes the level of efforts required to keep the system operational:

1	2	3	4	5
Additional workload is extreme	Additional workload is significant	Additional workload is acceptable	Additional workload is medium	Additional workload is minimal

6. Are the alarms loud enough to be heard in the work zone?

1	2	3	4	5
Unnoticeable	Difficult to hear	Audible	Loud	Very loud

7. Are the personal alarm devices worn by the workers loud enough to be heard in the work zone?

1	2	3	4	5
Unnoticeable	Difficult to hear	Audible	Loud	Very loud

8. Are the personal vibration-based alarms noticeable?

1	2	3	4	5
Unnoticeable	Difficult to notice	Average	Noticeable	Very noticeable

9. Please select the best option that describes the useability of the personal alarm devices:

1	2	3	4	5
Impossible to use in a work zone	Useable with substantial levels of burden and/or disruptions	Useable with acceptable levels of burden and/or disruptions	Useable with some minor burdens for workers	Highly useable

10. Please select the best option that describes the effectiveness of the work zone intrusion detection and alerts (you can skip if no work zone intrusion occurred during the tests period):

1	2	3	4	5
No alert was generated at least in one case	Alerts generated with long delays	Alerts generated in a timely manner with acceptable delays	Alerts generated in a timely manner with minimal delays	Alerts generated in a timely manner without noticeable delays

11. Please indicate the use cases (types of projects) where the system can be potentially deployed (check all that apply):

Nature of work:

___Roadway pavement

___Utility repair/maintenance

___Roadway widening/construction

___Intersection signalization

Duration of work:

___Long-Term Stationary

___Intermediate-Term Stationary

___Short-Term Stationary

___Short Duration (work that occupies a location up to 1 hour)

___Continuously Moving Mobile Operations

___Intermittent Mobile Operations

Work Setting:

___Urban

___Rural

___Low Speed

___Intermediate Speed

___High Speed

___Low Traffic Volume

___Average Traffic Volume

___High Traffic Volume

Others:

12. Please select the best option that describes your assessment for the overall effectiveness of the system:

1	2	3	4	5
Infeasible technology for a typical use case	Requires substantial modification to become deployable in a typical use case	Effective and deployable in a typical use case with some modifications	Effective and deployable in a typical use case with minimal modifications	Effective and deployable in a typical use case as it is

13. Additional Comments: