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Designing a High-Accuracy, Fast-Response Electrical Work Zone Alerting System

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Abstract

An alerting system is essential for the safety of workers in construction work zones. This report describes the technical analysis, design, testing, and assessment of a precise and reasonably priced system that uses ultrasonic sensors and Arduino microcontrollers to detect errant vehicles and alert workers. Iterative development helped the system overcome challenges in managing software complexity and fine-tuning sensor accuracy, and real-world testing proved the system's capacity to improve worker safety by delivering prompt visual and audio alerts. The system is a valuable safety tool for construction zones, as evidenced by extensive evaluations confirming its adaptability and reliability under various conditions. Smaller construction companies can particularly benefit greatly from the system's affordability, user-friendliness, and ability to promptly alert workers of approaching vehicles and avert accidents that could result in injuries and fatalities.

Key findings

The system tested was found to provide:

- ***Enhanced Worker Safety:*** By promptly sending out visual and audio alerts, the system considerably lowers the likelihood of fatalities and injuries caused by errant vehicles in construction zones, thereby improving construction workers' safety compared to no alert system.
- ***Precision and Reliability:*** The system's accuracy and reliability in identifying oncoming cars have been thoroughly tested, producing accurate and consistent operation under various circumstances.
- ***Cost-Effectiveness:*** Combining ultrasonic sensors with Arduino microcontrollers makes a low-cost solution available to smaller construction companies.
- ***User-Friendly Integration:*** The system's user-friendly design makes integrating hardware components simple for construction workers, who can easily set up and operate it.
- ***Versatility and Adaptability:*** The system exhibits a high degree of versatility and adaptability, allowing it to be adjusted to various environmental factors and construction scenarios, guaranteeing thorough coverage and efficient alerts.

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Introduction

Across the country, aging and overcrowded roadways, increasing travel, and extreme weather regularly create the need for repairs, improvements, and expansions. Data from the federal Bureau of Transportation Statistics shows that between 1982 and 2012, Vehicle Miles Traveled (VMT) increased by 86%, but the total number of lane miles available to meet this demand only went up 7.4% (Mishra, 2021). Infrastructure funding from the federal government has accelerated road construction over the last several years.

This funding has led to thousands of work zones on America's streets and highways. Because of "daily changes in traffic patterns, narrowed rights-of-way, and other construction activities," crashes have occurred frequently in work zones (FHWA 2019). The complexity and diversity of hazards within these work zones has also increased significantly (Li et al., 2018). Construction and maintenance workers are at risk of fatal and nonfatal severe injuries when working near passing motorists, construction vehicles, and equipment.

As CPWR – The Center for Construction Research and Training has reported, road incidents, especially in highway work zones, are a significant contributor to the construction industry's high incident rates (CPWR, 2015). In 2020, the U.S. Department of Transportation's Fatal Analysis Reporting System (FARS) reported 857 fatalities in U.S. work zones: 117 of them were construction workers. The National Institute for Occupational Safety and Health (NIOSH) discovered that workers injured by a vehicle account for approximately half of all work zone fatalities in the construction industry (NIOSH, 2018). There were 1,092 fatal work injuries in the construction sector in 2022 (BLS, n.d.). Almost a quarter (23.9%) of these fatalities were caused by transportation-related incidents, and 5.3% occurred in road construction sites (BLS, n.d.).

The effects of work zone collisions extend beyond fatalities and injuries—it also significantly affects driver and traffic flow (Ullman et al., 2011). The government and motorists both suffer severe economic consequences, with work zones imposing delays and inconveniences, which reduce productivity and lengthen travel times. According to the Texas Transportation Institute, construction zone delays cost American motorists $13.5 billion in 2018 (Texas A&M Transportation Institute, 2019).

Because of all this, ensuring work zone safety has become a priority for transportation authorities—including the Federal Highway Administration (FHWA) and state departments of transportation (DOTs)—as well as the transportation sector and the public. There has been a significant amount of research and projects aimed at identifying the features and causes of work zone crashes, as well as solutions to decrease deaths and injuries (Yang et al., 2015). The speed of the intruding vehicle, the distance between the sensor and the worker, and the accuracy of a system for detecting intrusions and warning employees are the main factors in work zone crashes, according to analysis of those crashes (Thapa, 2021).

Roadway construction, repairs, and maintenance activities require continuous effort from all stakeholders to provide safe and efficient work zones. To mitigate risks, various measures have been implemented to safeguard employees and motorists from work zone fatalities. The FHWA and the American Road and Transportation Builders Association (ARTBA) have launched initiatives such as the National Work Zone Awareness Week and Turning Point to decrease the number of fatalities (Nnaji et al., 2020), but there is more to do. Developing and utilizing new technologies, such as work zone alerting systems, represents one of the main recommendations to reduce vehicle intrusion incidents (Al-Bayati et al., 2023).

This project focused on creating a work zone alarm that can detect intrusions and alert workers about them in real time. This type of system must meet certain technological criteria to be effective and user-friendly, such as understandable warning signals, appropriate coverage distance, and minimal false alarms. This project aimed to offer a cost-effective and efficient solution that lowered fatal and nonfatal injuries. There are other available intrusion detection systems on the market; however, our system has several advantages over them, including:

- Cost-Effectiveness: The proposed system is designed to be affordable, so smaller construction companies that might not have the funds for more costly alternatives can use it.
- User-Friendly Integration: Thanks to its straightforward setup and operation, construction workers can effortlessly integrate the proposed system into the work zone and manage the system without the need for complicated hardware.
- Accurate vehicle detection: Using fine-tuned ultrasonic sensors produces reliable and precise performance under a range of conditions.
- Improved Worker Safety: Timely visual and auditory alerts greatly reduce the possibility of accidents and fatalities in work zones caused by errant vehicles.

Objectives

The researchers worked to achieve three objectives as outlined in our proposal:

1. Conduct a technical analysis of available technology and select what is most appropriate for our system.
2. Design and develop a work zone alerting system.
3. Test and evaluate the work zone alerting system.

Methodology & Results

The following sections describe our approach, challenges, findings, and achievements for each of the three objectives.

Objective 1 – Conduct a technical analysis of available technology and select what is most appropriate for our system

The researchers conducted a careful analysis of commercially available technologies that might be suited to building a system to detect errant vehicles in construction work zones and alert workers at a cost low enough for small contractors. The team used a multi-phase evaluation process to assess functionality, accuracy, reliability, user-friendliness, and affordability. A range of sensor technologies, such as LIDAR, infrared, and ultrasonic sensors, were considered, as well as various microcontroller platforms, like Arduino and Raspberry Pi. Each technology was evaluated to make sure that, in terms of affordability and ease of integration, it satisfied the unique requirements of small contractors.

The initial step of this work involved detailing the system's functional requirements: identifying approaching vehicles in a work zone, alerting workers in a reliable, rapid manner, and doing so within the limited budgets of small construction contractors. Identification included accurate assessment of distance, angle, and speed, and deployment demanded simplicity in dynamic construction environments.

The team surveyed different types of sensors that could satisfy these demands. The effectiveness of LIDAR, infrared, and ultrasonic sensors in proximity detection led to their shortlisting. Because of their high cost or lack of range precision in the intended operating environment, LIDAR and infrared sensors were excluded, but the Ultrasonic Range Finder - LV-MaxSonar-EZ0 (MB1000)—an ultrasonic sensor—was selected due to its excellent beam pattern and high accuracy in measuring distance.

The researchers considered microcontroller platforms like Arduino and Raspberry Pi because of their processing power, ease of programming, and adaptability to various sensor inputs. The Arduino microcontroller was chosen because of its extensive library support, affordability, and user-friendliness. It offered a simpler interface for connecting and configuring the sensors than the more intricate Raspberry Pi, reducing development time and increasing accessibility for smaller contractors with fewer technical resources.

In summary, ultrasonic sensors and Arduino microcontroller programming were selected based on multiple essential factors:

- *Functionality:* The system promptly notifies workers when an approaching vehicle is detected and takes appropriate preventive action.
- *Precision and Reliability:* Ultrasonic sensors have a high degree of precision when measuring distance, which allows them to accurately warn construction workers of approaching cars and improve worker safety.
- *User-Friendly:* Without additional complicated hardware, the Arduino platform makes it simple to create interactive devices by allowing the control of external outputs using switches and sensors.
- *Affordability:* The suggested system is an economically viable solution because of its low cost, making it affordable for smaller construction firms.

The selected ultrasonic sensor, shown in Fig. 1, features the most comprehensive and sensitive beam pattern, along with a one-inch resolution (i.e., the ability to distinguish objects with a precision of one inch), making it one of the best in its class among LV units. Part of the EZ sensor line, it offers a 20 Hz read rate and can detect objects within a range of 6 to 254 inches, supporting both short- and long-range detection. Additionally, it provides multiple output options, including pulse-width, analog voltage, and RS232 serial communication. Due to these capabilities, the MB1000 is an excellent choice for applications like this detection system, which require high sensitivity, a wide detection beam, and reliable object detection.

Figure 1. Ultrasonic Sensor for Object Detection

Ultrasonic sensors and Arduino microcontroller programming software had to be integrated into the implementation process. The system had to gather data from sensors affixed to cones, send it to the microcontroller, and then alert construction workers to possible collisions. A set of standardized processes, comprising ideation/problem definition, conceptualization, and prototyping stages, were followed during the prototyping phase. This approach, which required communication, design, modeling, and deployment, ensured structure and consistency. Several obstacles appeared during development, with these two being the most important:

- *Fine-tuning sensor accuracy*: There were difficulties in using ultrasonic sensors to detect cars with the highest accuracy possible while reducing false positives. The team focused on fine-tuning the sensor calibration to achieve accurate measurements.
- *Complexity of software development*: It was challenging to program Arduino microcontrollers to communicate seamlessly with sensors. The team used iterative software development and testing to overcome this obstacle.

Objective 2 – Design and develop a work zone alerting system

The development of the work zone alerting system included two main steps: programming the microcontroller and modifying the alerting mechanism to respond to a vehicle's proximity to traffic control devices. The system's hardware, software, and sensors installed on traffic control devices—such as cones or barriers—are programmed to use microcontrollers to identify safety concerns and, when needed, activate alerting devices. The progress achieved in this step includes:

- *System Configuration:* The alerting system needs to identify errant vehicles approaching construction zones. The research team integrated the microcontroller programming hardware with sensors and developed software to receive sensor signals and initiate alarms.
- *Design of the Alerting Mechanism:* The alerting system is programmed to activate when vehicles approach work zones near traffic control devices. The system improves worker safety by producing visual and audible alerts using flashing lights and a speaker, as shown in Fig. 2.
- *Arduino Microcontroller Adaptability:* By utilizing the Arduino platform, the system combines hardware and software for microcontroller programming to integrate sensors to the alerting system in the construction zones, which improves the work zone alerting system's accuracy and responsiveness considering the Arduino's adaptability.

Fig. 2. Industrial Lamp Post LED Alarm

The work zone alerting system, shown in Fig. 3, advanced significantly over the development process, with an emphasis on sensor integration, alerting mechanism design, and the versatility of Arduino microcontroller programming for construction-related applications. To guarantee the alerting system's reliability and efficacy in various construction site scenarios, the focus was on developing the prototypes, streamlining algorithms, and conducting extensive testing.

Fig. 3. The designed work zone alerting system

<u>Objective 3 – Test and evaluate the work zone alerting system</u>

Testing of the system occurred in an iterative manner, with results collected in two phases, as described below.

Phase 1: Interim Results

Interim results from the development of the work zone alerting system indicated noteworthy advancements toward creating an efficient safety mechanism for construction work zones. The focus of this phase were the early stages of system design, prototype development, and preliminary testing (see Fig. 4). On traffic control devices sensors were positioned strategically, and the Arduino microcontrollers were configured to receive signals from these sensors. Figure 3 shows how the system was designed to identify when a vehicle approached the cones in the work zone so it could then sound an alert.

Using the Python programming language for the microcontrollers, the system (shown in Fig. 4) could recognize and alert workers to possible intruding vehicles by turning on flashing LEDs and a speaker. Preliminary experiments were conducted in Lawrence Technical University Parking Lot E, with encouraging results. The prototypes did a satisfactory job identifying cars getting close to the cones and responded promptly, sounding alarms when cars approached.

Fig. 4. The preliminary testing setup

Phase 2: Final Results and Analysis

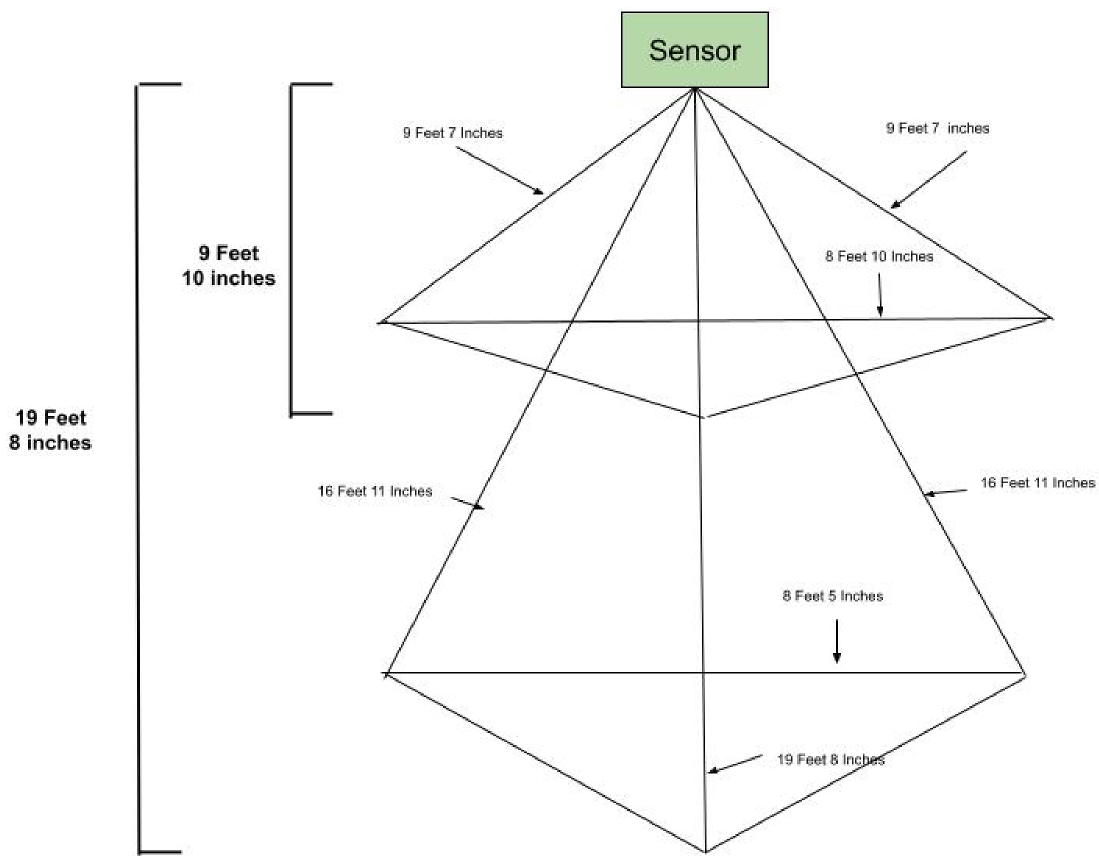
The team worked on improving the prototype, conducting extensive testing and using metrics evaluation to improve the system's reliability, accuracy, and flexibility in a range of situations. The team fine-tuned the prototype by adjusting the sensor and the microcontroller to guarantee accurate and reliable detection of vehicles approaching the work zone. The functionality of the proposed work zone alerting system was then validated through iterative testing in the construction work zone. Simultaneously, work improved the algorithms built into the system to improve responsiveness and precision in identifying possible intrusions close to cones and construction zones.

System coverage with different adjustments

Figure 5 shows the sensor arrangements with variations of both the angles and the coverage distance from the sensor. It is worth noting that various car speeds and the angles between the sensor and the intruding car were used in this experiment. The proposed work zone alerting system can cover a distance of up to 18 feet 8 inches. The team decided to test the system at two different distances: 9 feet 10 inches and 19 feet 8 inches. Fig. 5 shows that the sensor has good coverage of angles on both its right and left sides.

The first step in distributing the alarm systems is finding the length of the work zone transition section—that is, the part of the road where drivers are redirected from their normal path to a new route. We then divide the transition section's length (L) by the sensor's effective coverage distance. As seen in Fig. 5, we need to make sure that every alarm system is set for the best possible angle coverage, efficiently covering angles on both sides. Testing showed that the sensor's coverage in detecting objects is 45 degrees from both sides. Furthermore, we need to consider the different speeds at which employee vehicles or public cars and trucks could pass through the transition area, then modify the alarm systems' sensitivity appropriately.

Fig. 5. The sensor coverage with different adjustments



A low-cost solution, even with some imperfections, can provide smaller construction firms with a safety tool they would not otherwise have access to due to budget constraints. Furthermore, it is recommended that the system be installed within the buffer area, maintaining a minimum distance of 8 feet from the traveled lane. The buffer space is a lateral and/or longitudinal area that separates road user flow from the workspace or an unsafe area and might provide some recovery space for an errant vehicle. This recommendation is based on the following rationale:

- Buffer space separates road user flow from the workspace and might provide recovery space for an errant vehicle. Section 6B.06.07 of the Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways recommends that "neither work activity nor storage of equipment, vehicles, or materials should occur within a buffer space." This implies that the buffer space should remain entirely clear. Consequently, placing the alerting system within the buffer space will help significantly reduce the number of false alarms and increase its efficiency.
- As shown in Figure 5, the sensor's coverage range is approximately 6 feet on both sides. Therefore, maintaining an 8-foot distance from the traveled lane would help reduce false alarms.

Weather-based Testing 1 (Cloudy and Cold)

The two tests reported as Tables 1 and 2 were conducted in cloudy weather with a temperature of 44 degrees in mid-May. The team evaluated the accuracy and reliability of the warning system under extended-range circumstances in the 9 feet and 10 inches and 19 feet 8 inches experiments. The experiment data for the 9 feet 10 inches test is shown in Table 1. The testing was run at different time intervals with different speeds of the car. All 20 of the tests produced accurate results, confirming the system's reliability in identifying automobiles. These show how the system's improved accuracy and detection range can maintain safety in construction zones.

Table 1: 9 feet 10 inches Experiment - Cloudy Weather and 44 Degrees

Time	Experiment #	Accuracy (Y/N)
11:31	1	Y
11:31	2	Y
11:31	3	Y
11:32	4	Y
11:32	5	Y
11:32	6	Y
11:33	7	Y
11:33	8	Y
11:33	9	Y
11:34	10	Y
11:34	11	Y
11:35	12	Y
11:35	13	Y
11:36	14	Y
11:36	15	Y
11:36	16	Y
11:36	17	Y
11:37	18	Y
11:37	19	Y
11:37	20	Y

Table 2: 19 feet 8 inches Experiment - Cloudy Weather and 44 Degrees

Time	Experiment #	Accuracy (Y/N)
11:49	1	Y
11:49	2	Y
11:49	3	Y
11:50	4	Y
11:50	5	Y
11:50	6	Y
11:52	7	Y
11:52	8	Y
11:52	9	N
11:53	10	Y
11:53	11	Y
11:53	12	Y
11:53	13	Y
11:53	14	Y
11:53	15	N
11:54	16	Y
11:54	17	Y
11:55	18	Y
11:55	19	Y
11:55	20	Y

A thorough description of the 19 feet 8 inches experiment data is given in Table 2. Eighteen of the 20 experiments saw the system correctly identify car intrusion into the work zone, demonstrating high reliability.Nonetheless, there were two cases when the experiment results were not accurate (Experiments #9 and #15). The system's capacity to operate efficiently across longer distances validates the enhancements made to the sensor during Phase 2 of the project.

Table 3: 9 feet 10 inches Experiment – Sunny Weather and 91 degrees

Time	Experiment #	Accuracy (Y/N)
13:15	1	Y
13:15	2	Y
13:16	3	Y
13:16	4	Y
13:17	5	Y
13:17	6	Y
13:17	7	Y
13:18	8	Y
13:18	9	Y
13:19	10	N
13:20	11	Y
13:20	12	Y
13:20	13	Y
13:20	14	Y
13:20	15	Y
13:21	16	Y
13:21	17	Y
13:22	18	Y
13:22	19	Y
13:22	20	Y

Weather-based Testing 2 (Sunny and Hot)

The two tests shown in Tables 3 and 4 were carried out at 91 degrees in sunny weather in late June 2024. The 9 feet 10 inches test data, which is shown in Table 3, demonstrates constant accuracy throughout all trials. The tests were again run with different car speeds and time intervals. The results obtained from 19 of 20 tests again attested to the system's reliability. Table 4 highlights the system's 19 feet 8 inches performance: in 19 of the 20 experiments, the system correctly detected vehicle. This performance highlights the system's ability to operate effectively over longer distances, confirming the sensor improvements made during Phase 2 of the project. The comparison of these results with those in cloudy weather and a temperature of 44 degrees shows that weather conditions do not affect accuracy.

Cost-Effectiveness

There are multiple components involved in estimating the direct cost of the sensor, including labor, materials, and requirements:

- The ultrasonic sensor's cost: With features like a 20Hz read rate, a measurement range of 6 to 254 inches, and several output options, the MB1000 EZ sensor usually costs around $40.
- Arduino Microcontroller: Generally speaking, an Arduino microcontroller board that works with the MB1000 sensor costs around $30.
- Sensor and microcontroller enclosure: around $15.
- Batteries or power supply: around $10.

- Other Resources: Ten to twenty dollars for a breadboard, wires, resistors, capacitors, and other electronic parts.
- Labor Charges: Assuming that the labor requires programming, testing, and installation. Then, we can calculate the hourly rate of a proficient technician or engineer at around $40.

Comparison

This sub-section aims to compare the proposed work zone alerting system to others currently available.

Table 4: 19 feet 8 inches Experiment – Sunny Weather and 91 degrees

Time	Experiment #	Accuracy (Y/N)
13:40	1	Y
13:40	2	Y
13:41	3	Y
13:41	4	Y
13:41	5	Y
13:42	6	Y
13:42	7	Y
13:43	8	Y
13:43	9	Y
13:44	10	Y
13:44	11	Y
13:44	12	Y
13:45	13	Y
13:46	14	Y
13:46	15	Y
13:47	16	Y
13:47	17	Y
13:48	18	Y
13:49	19	N
13:49	20	Y

- The Transpo Industries' SonoBlaster® Dual Alert Work Zone Intrusion Alarm: A loud warning sound is activated when a barricade, cone, drum, or other traffic control device gets struck and knocked over. This device has several drawbacks, such as sounding frequent alarms when cars pass at higher speeds close to the work zone devices. Also, this system is mainly developed for flaggers, and it must be set up using a smartphone application. In addition, this alarm system has excessive life cycle costs for smaller contractors.
- Astro Optics, LLC's "Traffic Guard Worker Alert System" (WAS): An audio and visual alert is electronically triggered when a vehicle drives over a pneumatic hose. WAS suffers from issues that include a limited range of transmission, signal transmission delays, and non-real-time device tracking.
- IntelliStrobe Safety Systems, LLC: An audible alarm and a visual system go off when a vehicle crosses a pneumatic hose. The price of an Intellistrobe system is about $25,000. Although this

system is appropriate for low-speed work zones, in high-speed ones it struggles to provide workers with enough warning time because the alert system is close to the equipment.

- Highway Resource Solutions' (UK) Intellicone®: This system uses a traffic cone with a motion sensor attached to a lamp that can detect being struck by a car, at which point it sends out an auditory and visual alarm. The system has some drawbacks, including taking a while to set up, regular false alarms, and problems in the U.S. with network connectivity.

Because of the limitations of existing systems like these, the American construction industry does not consistently use an alarm system. The work zone alerting system produced by this research, however, offers enhanced overall safety measures: it provides a high rate of accuracy, lowers the technology cost, and emphasizes worker comprehension of the warning signal. It has other advantages compared to current technologies. It provides an economical and effective solution without extra hardware or infrastructure, such as smartphones and network connections and gives accurate alert rates with few to no false alarms. Overall, it improves safety in construction work zones, since it is accessible to workers with all technical knowledge thanks to its budget-friendly design.

Limitations

A primary constraint of the suggested instrument is its inability to distinguish between distinct items (such as multiple cars or a car and a worker), leading to the sounding of the alert for every object, potentially greatly escalating the number of false alarms. However, the system's low cost outweighs this drawback, allowing for widespread use, particularly by smaller construction companies. Determining the length of the transition section where the alarm systems must be installed is advised to maximize the alarm system's distribution.

Next Steps

The alarm could use a number of methods to inform workers in the construction work zone about intruding cars. In the proposed system, we used a wired system to alert the workers, with an LED Alarm Circular Tower Lamp with continuous light and a buzzer. However, alerts can also be received by mobile devices by SMS, calls, or app notifications. Instant audio notifications could be available on radios and are particularly helpful in busy construction sites. Wearable technology may alert workers to possible hazards by vibrating or making noises. Examples of these gadgets are smartwatches and customized alert bracelets. The efficacy of the warning system may be greatly increased by ensuring it is integrated with various communication tools. Workers may get timely notifications if the alert system is integrated with cutting-edge communication tools like Internet-of-Things (IoT) devices and real-time monitoring systems. Subsequent investigations may enhance the system's ability to distinguish between intruding objects to minimize false alerts. Creating more complex algorithms to improve the system's accuracy and responsiveness would be beneficial. Future studies might also examine machine learning methods to enhance item recognition and classification in the warning system.

Changes from the Original Scope

No changes to the original scope to report.

Deviation from Methods or Timeline

No deviation from methods or timeline.

Changes in Key Staff, Plans, or Methods

No changes in key staff, plans, or methods to report.

Publications & Presentations

The research team will work on possible journal publication/conference presentation.

References

Al-Bayati, A. J., Ali, M., Nnaji, C. (2023) "Managing Work Zone Safety during Road Maintenance and Construction Activities: Challenges and Opportunities." Practice Periodical on Structural Design and Construction, 28(1). https://doi.org/10.1061/PPSCFX.SCENG-1212.

CPWR, (2015). Temporary Workers in the Construction Industry. CPWR Quarterly Data Report. https://www.cpwr.com/wp-content/uploads/publications/publications_Second-Quarter-2015.pdf

CPWR. (2015). Reducing Highway Construction Fatalities Through Improved Adoption of Safety Technologies, https://www.cpwr.com/wp-content/uploads/Eseonu-reducing-highway-fatalities.pdf

Federal Highway Administration. 2023. Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) 11th Edition, December 2023

FHWA. (2019). "Work Zone Facts and Statistics." https://ops.fhwa.dot.gov/wz/resources/facts_stats.htm#ftn2.

Li, Q., Guo, F., & Gao, Y. (2018). Emerging safety issues and countermeasures in highway megaprojects. Safety Science, 103, 114-121. https://doi.org/10.1016/j.ssci.2017.11.001.

Li, Y., Hu, Y., Xia, B., Skitmore, M., amp; and Li, H. (2018). Proactive behavior-based system for controlling safety risks in urban highway construction megaprojects. Automation in Construction, 95, 118-128.

Mishra, Sabyasachee, Mihalis M. Golias, and Diwas Thapa. Work Zone Alert Systems. No. RES2019-01. Tennessee. Department of Transportation, 2021.

MVCDC, Motor Vehicle Crash Data Collection, (2022). [Online]. Available: https://www.nhtsa.gov/crash-data-systems/crash-report-sampling-system.

NIOSH. (2018). Highway work zone safety. National Institute for Occupational Safety and Health. https://www.cdc.gov/niosh/topics/highwayworkzones/default.html

Nnaji, C., Gambatese, J., Lee, H.W., Zhang, F., 2020. Improving construction work zone safety using technology: A systematic review of applicable technologies. Journal of traffic and transportation engineering 7(1), 61-75.

Texas A&M Transportation Institute. (2019). The 2019 Urban Mobility Report. Retrieved from https://static.tti.tamu.edu/tti.tamu.edu/documents/umr/archive/mobility-report-2019.pdf

Thapa, D., and Sabyasachee, M. (2021). "Using worker's naturalistic response to determine and analyze work zone crashes in the presence of work zone intrusion alert systems." Accident Analysis & Prevention 156 (2021): 106125.

Thapa, Diwas, and Sabyasachee Mishra. "Using worker's naturalistic response to determine and analyze work zone crashes in the presence of work zone intrusion alert systems." Accident Analysis & Prevention 156 (2021): 106125.

U.S. Bureau of Labor Statistics. (n.d.). Census of Fatal Occupational Injuries (2011 forward). [dataset]. https://www.bls.gov/iif/data.htm.

U.S. Department of Transportation Federal Highway Administration. (2019). Work Zone Safety. Retrieved from https://ops.fhwa.dot.gov/wz/resources/facts_stats.htm.

Ullman, G.L., Lomax, T.J., Scriba, T., 2011. A primer on work zone safety and mobility performance measurement. United States. Federal Highway Administration. Office of Operations.

Yang, H., Ozbay, K., Bartin, B., 2015a. Effectiveness of temporary rumble strips in alerting motorists in short-term surveying work zones. Journal of Transportation Engineering 141(10), 05015003.