NCHRP Project 20-07/Task 416:
Available Technologies and Recommended Technology Adoption and Implementation Practices for Mitigating Work Zone Intrusions

This technical memorandum provides information about available technologies that can be used for preventing or mitigating work zone intrusions along with recommendations for adopting and implementing the technologies. The memorandum is an output of NCHRP Project 20-07, Task 416, "Alternative Technologies for Mitigating the Risk of Injuries and Deaths in Work Zones." The memorandum is intended to provide state departments of transportation (DOTs) with guidance on work zone intrusion technologies (WZITs) to facilitate their selection and use, and ultimately help prevent motorist and worker injuries and fatalities in roadway work zones.

Protecting the health and safety of transportation infrastructure users and those who construct and maintain it is of utmost importance. Safety is the top priority when planning, designing, constructing, and maintaining our roadways. All too often, injuries and fatalities occur due to crashes in work zones on roadways. The crashes are often the result of vehicle intrusions into temporary roadway work zones. The intrusions may result in injuries and deaths to the motorists and workers. Prevention and mitigation of work zone intrusions is a high priority for improving work zone safety.

Available and Recommended Work Zone Intrusion Technologies

Technology provides an opportunity to enhance work zone safety. It can collect and communicate work zone and traffic data in real-time, reduce worker exposure to hazards, and protect workers from hazards. Work zone intrusion technologies are available that aid in preventing vehicle intrusions into roadway work zones and mitigating the impacts of the intrusions when they occur. The technologies are designed to perform one or more of the following functions: warn workers and drivers of a potential intrusion; provide a barrier to prevent an intrusion; detect and alert drivers and workers during an intrusion; and protect workers and drivers following an intrusion.

Based on a comprehensive technology search and evaluation, the following technologies are applicable to preventing and mitigating work zone intrusions, and considered to be sufficiently mature and ready to use on roadway projects:

- ***Motorist Vehicle Systems:*** Motorist vehicle systems refers to those technologies in which the safety application is in-part embedded in the passing vehicles. The technologies utilized help to prevent vehicle intrusion by improving real-time driver awareness through the use of a warning message or a notification to the drivers as they enter a work zone. An alert message is also commonly sent to the workers who may be affected if an intrusion occurs. The specific technologies in this category are: autonomous vehicles and connected vehicles.

- ***Construction Equipment Systems:*** Highway workers utilize various types of equipment to complete the construction work operations. Recent developments have been made in utilizing technologies within and attached to the construction equipment to alert and protect the equipment operators and the workers on the roadway near the equipment when an

intrusion occurs. This type of technology is a relatively new class of work zone intrusion systems, and is termed "construction equipment systems." This category includes: autonomous equipment, connected equipment, autonomous equipment with truck-mounted attenuators, mobile barriers, and automated flagger with intrusion alert device.

- ***Unmanned Aerial Systems:*** Unmanned aerial systems (UASs) are completely mechanicalized aircraft systems consisting of three components: an autonomous or human-operated control system which is usually on the ground or a ship, but may be on another airborne platform; an unmanned aerial vehicle (UAV); and a command and control (C2) system - sometimes referred to as a communication, command, and control (C3) system to communicate with the remote user. The UAS system applicable to mitigating work zone intrusions is a UAS for signage and monitoring. The system consists of a UAV along with a camera system that provides real-time traffic monitoring with high temporal and spatial resolution which helps to dynamically manage the work-zone by interacting real-time with changeable message boards, driver mobile phones, and traffic management center and law enforcement agencies.[1]

- ***Intrusion Detection and Alert Systems:*** A more mature class of technologies that has been researched and developed, and is more widely available, is intrusion detection and alert systems, or simply abbreviated as IAS. The IAS concept is based on installing the technologies primarily on temporary traffic control devices. Some new IASs are standalone technologies that can be used in and around work zones to provide safety to the workers and/or the motorists who intrude in a work zone. Examples of IASs include: intrusion alert system with equipment-mounted sensors (e.g., AWARE), intrusion alert system with cone/barrel-mounted sensors (e.g., Sonoblaster), intrusion alert system with networked cone/barrel system with sensors (e.g., Intellicone), intrusion alert system with pneumatic tubes (e.g., Worker Alert System), intrusion alert system with Bluetooth, Intrusion detection with computer vision and ranging (e.g., SmartCone), intrusion alert system with radio frequency identification (RFID), and queue warning system with networked cone/barrel system (e.g., iCone System).

- ***Enhanced Signage and Enforcement:*** Innovative technologies that utilize visual attraction to notify motorists of upcoming work zones, and local law enforcement presence around the work zones to lower vehicle speed, have been developed over the past few decades. These types of technologies, which typically lead to a positive influence on driver behavior, include: work zone warning with dynamic message system (DMS), speed warning with dynamic message system (DMS), speed enforcement with radar, and speed enforcement with photo radar.

- ***Wearables:*** The use of personal wearable devices by workers helps the workers to visualize the work area and be visible to drivers in the event of a vehicle intrusion during nighttime work. This technology class has recently been getting attention as it involves advanced technological methods which have potential benefits to safeguard workers in the work

[1] Malveaux, C., De Queiroz, M., Li, X., Hassan, H., and He, Z. (2020). "Real-Time Work Zone Traffic Management via Unmanned Air Vehicles." Louisiana State University and A&M College, Transportation Consortium of South-Central States (Tran-SET), Retrieved from https://digitalcommons.lsu.edu/transet_pubs/70.

zone. The following types of technologies in this category are: wearable lighting (e.g., Halo light), head-mounted augmented reality (AR) display, smart watches/bracelets, and smart vests.

- ***Other Potential Technologies:*** New developments in technology and technological concepts that are yet to be developed provide promising opportunities for future work zone intrusion technologies. These potential future technologies include enhancing worker safety through simulations and device-free localization (DFL), and robot-controlled automated flagger stations. The technologies are presently in the spectrum of initial stages of research and development.

The technologies that are rated high in terms of effectiveness by industry personnel familiar with the technologies include:

- Positive protection measures, including automated equipment with truck-mounted attenuator, and mobile barriers
- Intrusion detection and alert systems, including automated flagger with intrusion alert, UAS for signage, equipment-mounted intrusion alert systems, and intrusion detection with computer vision and ranging

These WZITs are individually capable of performing specific functions associated with an intrusion. However, effectively preventing and mitigating work zone intrusions on a project requires performing multiple functions before, during, and after an intrusion occurs. Therefore, given the present limitations of each of the technologies, fulfilling all of these functions requires implementing a suite of diverse WZITs rather than one single WZIT.

Recommended Practices: WZIT Adoption, Selection, and Implementation

Adoption of a technology within an organization is a decision made by those with authority over the organization. When deciding whether to adopt a new technology, multiple factors are often considered. Adoption factors are the qualities, features, and conditions deemed important in the assessment of a technology when considering whether to acquire and implement the technology. Adoption factors are technology-related, organization-related, and externally-related. Those adoption factors that are considered particularly important for when evaluating WZITs are:

- Technology-related adoption factors:
    - Level of resistance to environmental impact
    - Having the required features/technical attributes
    - Level of technical support required
    - Ability of warning to alert driver/motorist
    - Ability of warning to alert worker
    - Alarm coverage distance
    - Frequency of false alarms
    - Types of warning alert sources provided (e.g., visual, audio, haptic)
    - Durability

    - Level of complexity (ease of deployment, movement, retrieval, maintenance, storage)
    - Ability to limit worker exposure to traffic
- Organization-related adoption factors:
    - Level of technical support available
    - Level of training required
    - Potential level of resistance from employees
    - How quick users will be able to influence colleagues
    - Potential cost savings from using the technology
    - Level of compatibility with current processes
    - Competitive advantage derived from using the technology
    - Top management degree of involvement
    - Cost of labor, equipment, maintenance
- Externally-related adoption factors:
    - Industry-level change requires technology adoption
    - Government policy and regulation
    - Direct competitors adopt similar technology

To increase adoption throughout the industry, greater effort and resources are needed to educate industry personnel about the available WZITs. Additional resources may need to be allocated by state DOTs outside of specific projects for a technology awareness/training program to support the adoption process. The program should target those WZITs for which there is presently a low level of familiarity within DOT and contractor personnel.

Organizations may pursue a variety of strategies to ensure successful adoption of a promising technology. Those strategies that have been identified as particularly effective means for enhancing adoption of WZITs are:

- Standards and regulatory-based strategies:
    - Mandatory work zone safety technology policies and regulations
    - Better enforcement of work zone traffic control policies after the WZITs have been implemented
    - More WZIT adoption advocacy by the Federal Highway Authority
    - Availability of competent and proactive WZIT promotion teams and local authorities
- Awareness-based strategies:
    - WZIT-related educational and training programs for vendors, contractors, DOTs, and policy makers
    - Availability to collect information on cost and benefits of WZIT
    - Publicity through media
    - Creation of public highway safety awareness through workshops, seminars, and conferences
- Financial incentive-based strategies:
    - Strengthened WZIT research and development through additional research investment
    - Financial incentives for WZIT adoption

- Operations-based strategies:
    - Support from executive management within the firm/organization
    - Employee involvement in implementation decision-making
    - Inclusion of specific technology requirements in contracts
    - WZIT assessment programs
    - Availability of institutional framework for effective WZIT implementation

Once a technology is adopted within an organization, selection of the technology for use on a specific project should include consideration of:

- Desired technology features and functionality:
    - Perimeter monitoring
    - Location monitoring (e.g., where the intrusion through the perimeter has occurred)
    - Issue warning to workers and/or drivers
    - Intrusion prevention (e.g., positive barrier)
    - Intrusion mitigation (e.g., lessen the impact after an intrusion occurs)
    - Connectivity to work zone infrastructure and personnel
- Intended technology application:
    - Location of technology in work zone
    - Placement of technology (on equipment, roadway surface, roadway infrastructure, or worker)
    - Timing of technology deployment (during mobilization, work performance, demobilization, or other)
    - Type of work zone (mobile, stationary, other)
    - Duration of work zone (long-term, short-term)
    - Type of work (construction, maintenance)
    - Roadway conditions (dry, wet, icy, or other)
    - Time of day (daytime, nighttime)
    - Type of work activity (paving, striping, road widening, or other)
    - Location of work activity (on travel lane, on shoulder, or other)
    - Vehicle speed in work zone
    - Roadway location (urban, suburban, rural)
    - Roadway type (local street, arterial roadway, highway, expressway/freeway)
    - Number of lanes
    - Roadway separation (divided, undivided)

Supporting Resources

The following resources developed from the research study are available to assist state DOTs and contractors with identifying WZITs to implement on projects.

- ***Work Zone Intrusion Technology Decision Support System:*** An online decision support system (DSS) is available that provides an easy-to-use and practical means of utilizing the information available related to WZITs. The DSS is specifically geared towards DOTs and contractors who might want a list of technologies that could be used on their project and

which meets the specific project conditions and work operations. The link to the DSS is available to interested parties from NCHRP upon request.

- ***Work Zone Intrusion Technology Guidebook***: The WZIT Guidebook provides a comprehensive resource regarding preventing and mitigating work zone intrusions using technologies. It includes information regarding the causes of work zone intrusions, describes potential technological solutions, and describes the decision support system. The guidebook includes the following content:

    - Chapter 1: An introduction to the document, its purpose, and intended audience.
    - Chapter 2: Background information on the safety concerns associated with work zone intrusions, including the various aspects of work zone intrusions from an analysis of previous incidents.
    - Chapter 3: Detailed descriptions of 15 technologies deemed effective at mitigating work zone intrusions. The information provided for each technology includes: (1) technology description; (2) current and potential work zone applications; (3) effectiveness; and (4) implementation guidelines. The technologies are classified based on their major functionality into one of three groups: Positive Protection Systems, Worker Warning Systems, and Driver Warning Systems.
    - Chapter 4: A description of the web-based decision support system (DSS) that allows users to select from various project, technology, and implementation constraints and view a list of applicable technologies that are arranged in order of suitability.

Recommended Document Updates

To support the implementation of the study results, the following national-level documents can be updated to incorporate relevant research findings. The recommended revisions/additions apply to a variety of chapters and/or sections related to work zone traffic control. The list is not exhaustive; other state- and national-level documents that are frequently utilized by agency personnel could benefit from revised/additional content as well.

- ***Highway Safety Manual (HSM)[2]:*** The HSM provides content that relates to work zones and temporary traffic control devices in the following sections: Section 16.4 – Crash Effects of Work Zone Design Elements, Section 16A.3 – Work Zone Design Elements, Section 16A.4.1 – Work Zone Traffic Control and Operational Elements, Section 16A.6 – Treatments with Unknown Crash Effects. The HSM presently contains limited information about technologies used in work zones, especially those technologies that are designed for preventing and mitigating work zone intrusions. In addition, the information provided does not specifically address use of the technologies for preventing/mitigating work zone intrusions. Those technologies mentioned in the HSM that are recognized as potential WZITs are: temporary rumble strips, changeable message signs, drones (unmanned aerial vehicle), and drones equipped with radar for speed monitoring and enforcement. The

[2] AASHTO (2010). *Highway Safety Manual*. American Association of State Highway and Transportation Officials (AASHTO), Washington, DC.

research team recommends revising the HSM to include more information about the available WZITs and their application.

- ***Manual on Uniform Traffic Control Devices (MUTCD)[3]:*** The MUTCD states that intrusion warning devices may be used to alert workers to the approach of errant vehicles (Section 6D.03). While the MUTCD provides guidance on how to implement traditional traffic control devices, there is no guideline or regulation supporting the implementation of intrusion alert technologies. The researchers recommend expanding the discussion of intrusion alert technologies into the MUTCD. Including these devices in the MUTCD will provide support for the use of WZITs and encourage and grow their development and implementation.

[3] FHWA (2009). *Manual on Uniform Traffic Control Devices for Streets and Highways*. U.S., Department of Transportation (USDOT), Federal Highway Administration (FHWA).