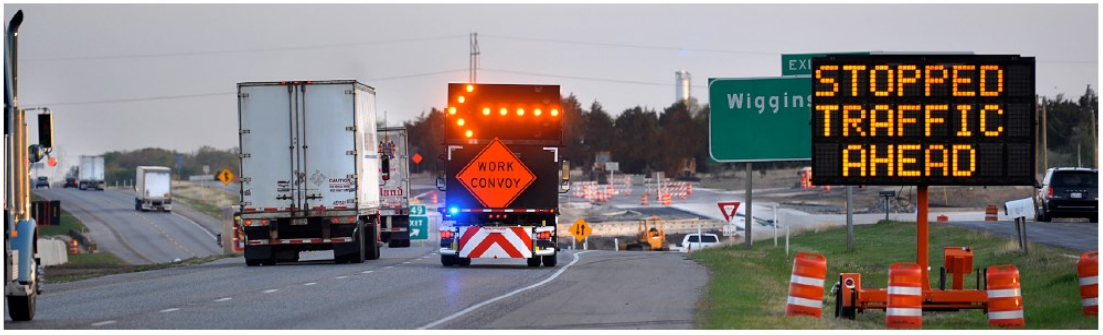

SYNTHESES OF RESEARCH RELATED TO
THE USE AND IMPLEMENTATION OF

Advanced Technology to Improve Work Zone Management

Texas A&M Transportation Institute

ARTBA American Road & Transportation Builders Association

U.S. Department of Transportation
Federal Highway Administration

June 2022 Update

Work Zone Safety Consortium
This material is based upon work supported by the
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List of Acronyms

ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AFAD	automated flagger assistance device
AIPV	automated impact protection vehicle
AMT	autonomous maintenance technology
API	application program interface
ATMA	automated truck-mounted attenuator
AV	automated vehicle
BLE	Bluetooth low energy
CALTRANS	California Department of Transportation
CAMP	Crash Avoidance Metrics Partners
CARMA	Cooperative Automation Research Mobility Application
CV	connected vehicle
DSRC	dedicated short-range communications
DOT	Department of Transportation
EDCM	event-driven configurable messaging
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRATIS	Freight Advanced Traveler Information Systems
IOO	infrastructure owner operator
ITS JPO	Intelligent Transportation Systems Joint Program Office
JSON	JavaScript Object Notation
MTC	Metropolitan Transportation Commission
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
OBU	on-board unit
QA/QW	Queue Advisory/Queue Warning
RSM	roadway safety message
RSZW/LC	reduced speed zone warning/lane closure
RSU	roadside unit
SAE	Society of Automotive Engineers
SwRI	Southwest Research Institute
TIDC	Traveler Information during Construction
TIM	traffic information message
TMC	transportation management center
TTC	temporary traffic control
TTI	Texas A&M Transportation Institute
USDOT	United States Department of Transportation
UWB	ultra-wide band
VCC	Virginia Connected Corridors
VTRC	Virginia Transportation Research Council
VTTI	Virginia Tech Transportation Institute
WZDI	Work Zone Data Initiative

WZDx	Work Zone Data Exchange
WZW	work zone warning

INTRODUCTION

Connected and automated vehicle technologies are advancing at a rapid pace. Connected vehicles (CVs) wirelessly communicate with each other and with the roadway infrastructure safely and seamlessly. Automated vehicles (AVs) automatically sense their environment and perform some or all driving functions normally performed by the human driver. The Society of Automotive Engineers (SAE) has defined 6 levels of driving automation, as summarized in Table 1. In SAE levels 0 through 2, the driver remains engaged and performs driving tasks as needed but is supported with different types of Advanced Driver Assistance Systems (ADAS). SAE levels 3 through 5 are supported by Automated Driving Systems (ADS). At these levels of automation, the vehicle performs all driving functions when engaged.

Table 1. Capabilities and Operations of Different Levels of Driving Automation.

Level of Driving Automation		Capabilities and Operations
Advanced Driver Assistance Systems (ADAS)	• SAE level 0 • SAE level 1 • SAE level 2	• Provides warnings and momentary assistance to drivers (emergency braking, blind spot warning, etc.), driver maintains full control of the vehicle • Assists driver with either steering or braking/acceleration tasks, driver maintains control of the vehicle • Assists driver with both steering and braking/acceleration tasks, driver remains engaged in the operation of the vehicle
Automated Driving Systems (ADS)	• SAE level 3 • SAE level 4 • SAE level 5	• Fully automated vehicle control in some situations, driver must take control of vehicle when the system requests • Fully automated control in defined, controlled operational design domains (ODDs) • Fully automated control in all situations

Source: Adapted from Society of Automotive Engineers

CVs and AVs offer the potential to reduce crashes, improve mobility, and enhance traveler comfort and productivity. However, the extent to which these improvements can be realized will depend on how well the technologies are able to establish and maintain accurate and timely situational awareness of the roadway environment as the vehicles move from point to point, including temporary changes to that environment caused by work zones.

Work zones can create several types of temporary changes to the roadway environment:

> Temporary changes to the base roadway map – Work zones often involve the temporary closure of travel lanes, turning bays, and driveways. Work zones can also temporarily change the way that a lane is utilized (e.g., converting a through-only lane to a through-turn lane because the adjacent “turn only” lane is closed for work activities). Work zones

that involve pavement widening may include lane shifts which move travel lane lines used by ADS several feet laterally from their original locations.

- Temporary changes to traffic control devices and regulations – Work zones often require temporary changes to certain traffic regulations and controls used on the roadway. These temporary changes include reduced speed limits, restricted turning movements at certain locations, and the addition of portable traffic signals, flaggers, or automated flagger assistance devices (AFADs) onto the roadway.
- Temporary addition of hazards into the driving environment – Work zones involve workers, equipment, barriers, materials, and other objects operating in and adjacent to the work area. The location and movement of these work zone components are often dynamic, sometimes causing them to encroach slightly on the adjacent travel lane.
- Temporary changes to operating conditions – Changes to the roadway environment listed in the three previous bullets often result in different operating conditions on the roadways where the work zone is located. These changes include slower travel speeds, the generation of traffic queues, different traffic signal timings, and driver unfamiliarity with turning movements at locations that differ from pre-work zone locations.

Efforts are currently underway to develop and test ways to support CV and AV operations approaching and passing through work zones. Efforts are also underway to explore how wireless communications and other advanced technologies can improve work zone safety and mobility for human drivers and workers as well. This synthesis has been developed to identify and summarize the various efforts underway regarding CVs, AVs, and other advanced technologies for improving work zone safety and mobility. The synthesis covers the following categories:

- Efforts to Define and Collect Digital Work Zone Event Data
- Non-CV Efforts to Disseminate Work Zone Event Data to Human Drivers
- CV Pilot Tests and Demonstrations that include Work Zone Components
- Efforts to Support ADS Accommodation of Work Zones
- Efforts to Utilize Advanced Technologies to Improve Worker Safety in Work Zones
- Other Initiatives

The synthesis provides an effort-by-effort synopsis of the following:

- Title of the activity
- Entities involved
- Overall description of the effort
- Specific work zone involvement in the effort
- Key work zone-related findings or lessons learned to date
- Contact(s) for more information

EFFORTS TO DEFINE AND COLLECT DIGITAL WORK ZONE EVENT DATA

Work Zone Data Initiative/Work Zone Data Exchange

Entities Involved: Federal Highway Administration (FHWA), USDOT Intelligent Transportation Systems Joint Program Office (ITS JPO)

Description of Effort: The purpose of the Work Zone Data Initiative (WZDI) is to develop a recommended practice for managing work zone event data (WZED) and to create a consistent language, through the development of a data dictionary and supporting implementation documents, for communicating information on work zone events across jurisdictional and organizational boundaries. An early implementation effort from that initiative is the Work Zone Data Exchange (WZDx) specification. The use of the specification enables infrastructure owners and operators (IOOs) to make harmonized work zone data available for third party use. The intent is to make travel on public roads safer and more efficient through ubiquitous access to data on work zone event information. Specifically, the project aims to get data on work zones into vehicles to help ADS, and human drivers navigate more safely.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Findings or Lessons Learned to Date: Version 4.0 of the WZDx specification is available for use. An Early Adopters' Guide is available to assist IOOs striving to develop and WZDx-compliant data feed. Demonstration grants have been awarded to 13 states to facilitate development of consistent public work zone data feeds across jurisdictions. Project highlights for three of the grantees (Wisconsin, Colorado, Iowa) have been prepared and are available on the demonstration grant website below.

Contacts: ITS JPO - avdx@dot.gov
https://ops.fhwa.dot.gov/publications/fhwahop18083/index.htm
https://ops.fhwa.dot.gov/wz/wzdx/demonstration_grants.htm
https://github.com/usdot-jpo-ode/jpo-wzdx

Piloting Smart Work Zone Technologies to Provide Real-Time Lane Closure Information to Improve Oregon Highway Safety and Mobility

Entities Involved: Oregon State University, Oregon Department of Transportation (DOT).

Description of Effort: The research goal of piloting the use of smart work zone technologies to obtain real-time work zone lane closure information will be obtained by pursuing the following specific objectives: (1) pilot the selected smart work zone technologies to identify and

recommend new Oregon DOT policies and standards, (2) demonstrate methods to provide real-time, accurate work zone data to Oregon DOT's TripCheck.com traveler information website, (3) demonstrate methods to provide high-fidelity real time work-zone lane closure data to the ODOT project of automated over-dimension permitting system, and (4) demonstrate methods to provide real time lane impacted data via Oregon DOT's work zone data exchange compliant data feed.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Haizhong Wang, Oregon State University

Real-Time Integration of Arrow Board Messages into Traveler Information Systems

Entities Involved: ENTERPRISE Pooled-Fund Program, Minnesota DOT

Description of Effort: Work has been undertaken to generate a model concept of operations and model requirements for a system to report arrow board status information (location and operational mode) back to a transportation management center (TMC) in order to provide improved real-time information to travelers and documentation of actual work activity locations and times. The automatic creation of digital work zone event data can also be easily consumed by third-party navigation companies (WAZE, Google, HERE, etc.). An evaluation plan was also prepared, and an evaluation performed based on that plan.

Specific Work Zone Involvement: The project was completely work zone focused.

Key Findings or Lessons Learned to Date: Multiple vendors have or are developing smart arrow board technology. Although slight differences exist in how the technology functions from vendor to vendor, DOT staff from Minnesota and Iowa indicated that the availability of this information was beneficial for travelers and provided improved information to TMC operators about the location of lane closures. The availability of real-time digital data regarding the location of lane closures via this type of technology will be critical to successful accommodation of CVs and AVs through work zones in the future.

Contacts: Tina Roelofs, Athey Creek
http://enterprise.prog.org/Projects/2020/arrowboard_messages_into_travel_info_phase3-final_report.pdf

Smart Arrow Board Deployment Plan

Entities Involved: Iowa DOT

Description of Effort: The Iowa DOT has initiated an effort to require all arrow boards used on multi-lane agency roadways be able to automatically communicate location and operational status in real time. Initial deployment is focusing on interstates, with deployment on other multi-lane roadways to follow. A needs/requirements analysis has been completed, and two smart arrow board protocols have been defined. One protocol option focuses on receiving data from the arrow board vendor (or data representative) who polls its arrow boards and provides a data stream using a JavaScript Object Notation (JSON) data-interchange format. The other protocol option focuses on receiving data directly from each smart arrow board itself.

Specific Work Zone Involvement: The project was completely work zone focused.

Key Findings or Lessons Learned to Date: The provision of two protocols was deemed necessary to provide contractors the flexibility needed to procure new smart arrow boards or to retrofit existing ones.

Contacts: Dan Sprengeler and Willie Sorenson, Iowa DOT
https://iowadot.gov/workzonereferencelibrary/docs/Smart-Arrow-Board-Deployment-Plan.pdf

Event-Driven Configurable Messaging (EDCM) Design and Development and Work Zone Queue Advisory/Queue Warning (QA/QW) System

Entities Involved: Crash Avoidance Metrics Partners (CAMP), FHWA

Description of Effort: CAMP and FHWA are working to develop a flexible message scheme with the ability to dynamically adjust two-way data exchange between connected vehicles and a Traffic Management Center.

Specific Work Zone Involvement: Queues occurring at work zones are a focus area of this effort.

Key Work Zone-Related Findings or Lessons Learned to Date: Descriptions of the overall project development process, concept of operations, requirements, and XML schema are available on the website.

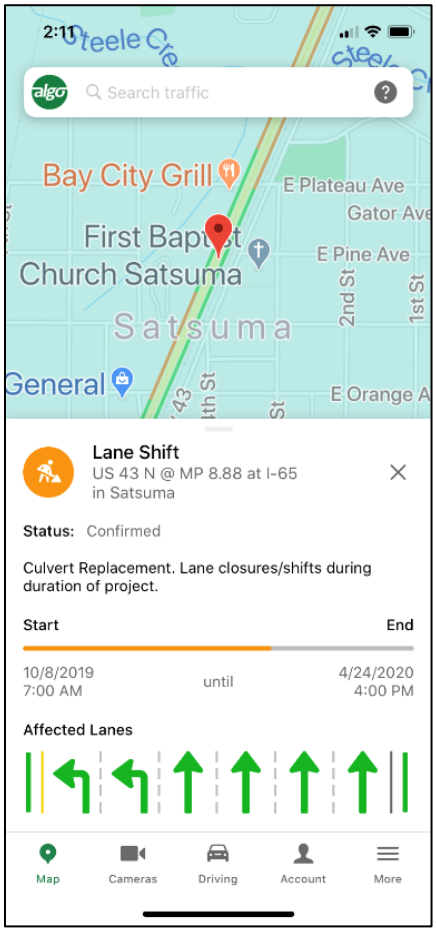
Contacts: Jay Parikh, CAMP
http://www.campllc.org/event-driven-configurable-messaging-edcm-design-development-and-work-zone-queue-advisory-warning-qa-qw-system/

NON-CV EFFORTS TO DISSEMINATE WORK ZONE EVENT DATA TO HUMAN DRIVERS

Alabama Work Zone Incident Notification System

Entities Involved: Federal Motor Carrier Safety Administration (FMCSA), Alabama DOT, Alabama Law Enforcement Agency, Center for Advanced Public Safety

Description of Effort: A work zone notification system was developed on both Android and iOS mobile platforms to provide rolling reminders to the user about the location of downstream work zones and estimated distance to each work zone (see Figure 1). This capability was incorporated into the Alabama DOT traveler information system (ALGO Traffic).



Source: algotraffic.com

Figure 1. ALGO work zone notification app.

Specific Work Zone Involvement: See above

Key Work Zone-Related Findings or Lessons Learned to Date: Phase II of the effort is still underway.

Contacts: Thomas Kelly, FMCSA
https://algotraffic.com

Arizona Work Zone and Incident Electronic Notification System

Entities Involved: FMCSA, Arizona DOT, Maricopa County, Maricopa Association of Governments, University of Arizona, DriveWyze, Knight-Swift Transportation, consultants

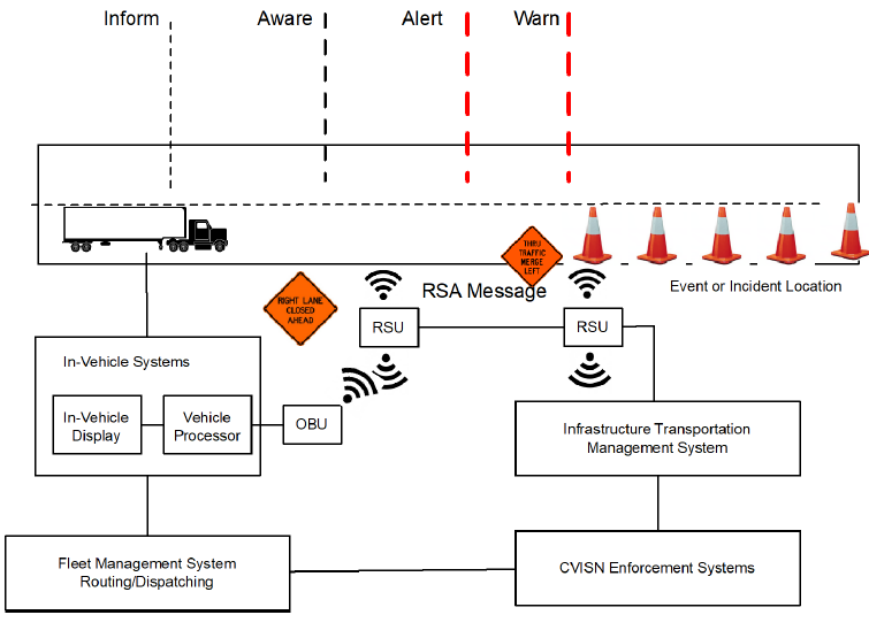
Description of Effort: A system was created to demonstrate a work zone warning and alert system to provide in-vehicle information to commercial vehicle operators. Location of work zones, weather alerts, other emergency and 511 alerts were presented into the cab of the large commercial vehicles. Version 1.1 of the Work Zone Data Exchange (WZDx) specification was followed in the formatting of work zone information.

Specific Work Zone Involvement: As illustrated in Figure 2, the system concept integrates existing information sources about work zone locations (where options to take alternative routes exist) with connected vehicle data to improve driver situational awareness of a work zone they are approaching, alert them about work zone hazards and conditions ahead, and warn them of any unexpected events (i.e., a construction vehicle that is entering the roadway).

Although some testing of RSU capabilities was conducted, Arizona DOT and Maricopa County DOT decided to wait for technology to mature before deploying a separate CV demonstration using separate OBUs and RSUs. Rather, they created an application program interface (API) using the WZDx version 1.0 specification that an existing provider of in-cab information to commercial motor vehicles could consume and disseminate via its equipment.

Key Work Zone-Related Findings or Lessons Learned to Date: Some challenges arose as to how best to implement the WZDx specification in certain situations such as repeating daily off-peak lane closures, or when work zone conditions remain constant while workers arrive and leave periodically. Questions also arose as to how to use the specification to represent a center-two-way-left-turn lane.

Contacts: Thomas Kelly, FMCSA
https://rosap.ntl.bts.gov/view/dot/49221



Source: University of Arizona

Figure 2. Initial concept for the Arizona work zone notification system.

Kentucky Work Zone Notification System

Entities Involved: FMCSA, Commonwealth of Kentucky

Description of Effort: Similar to above efforts, a system is being developed to provide in-cab notifications to commercial motor vehicle drivers of the presence of various hazards that will be encountered as they drive the roadway network.

Specific Work Zone Involvement: Presence of an active work zone is slated to be one of the conditions that drivers will be notified about as they approach the location.

Key Findings or Lessons Learned to Date: This project has just begun.

Contacts: Thomas Kelly, FMCSA
https://rosap.ntl.bts.gov/view/dot/49221

Commercial Vehicle Slowdown Alerts

Entities Involved: North Carolina DOT, Drivewyze, INRIX

Description of Effort: Commercial vehicle operators using the Drivewyze electronic logging devices will receive automated alerts when slowdowns are detected downstream of the vehicle

(see Figure 3). Traffic slowdowns are determined using real-time probe speed data provided by INRIX. General warning messages are also being issued to drivers approaching geo-fenced work zones. A one-year pilot program was initiated in May 2021 followed by an evaluation of the data to determine the effectiveness of the system.

Source: North Carolina DOT

Figure 3. Display of commercial vehicle slowdown alert.

Specific Work Zone Involvement: Traffic slowdowns from all causes, including work zones will be included in the alerts that are disseminated.

Key Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Kelly Wells, North Carolina DOT

Test and Evaluate a Bluetooth-Based In-Vehicle Message System to Alert Motorists in Work Zones

Entities Involved: University of Minnesota

Description of Effort: A prototype system was developed to provide in-vehicle safety-critical and pertinent work zone messages. The system uses inexpensive Bluetooth low energy (BLE) beacons that can be deployed in or ahead of the work zone. A smartphone app, called WorkzoneAlert, was developed to trigger non-distracting, auditory messages in a smartphone mounted in a vehicle within range of the BLE beacons. Messages associated with BLE beacons around the work zone can be updated remotely in real time.

Specific Work Zone Involvement: The project focused entirely on a work zone application.

Key Findings or Lessons Learned to Date: The WorkzoneAlert app was found to be able to detect the BLE beacon and successfully announce the message associated with the beacon an average of 127 meters away.

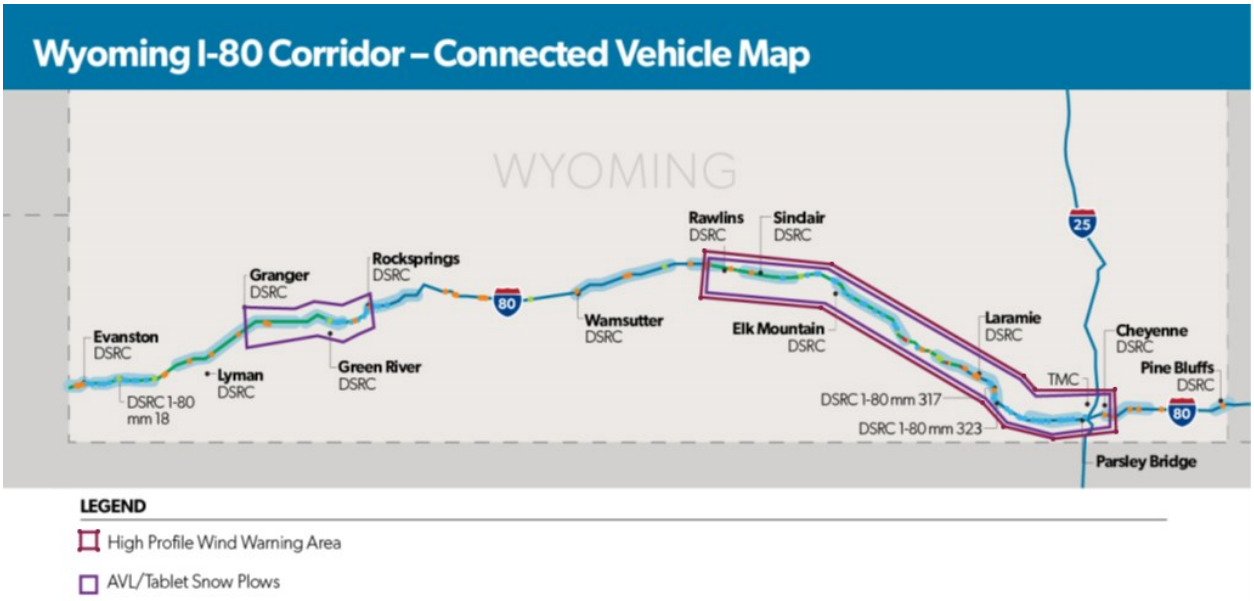
Contacts: Chen-Fu Liao, University of Minnesota
http://www.roadwaysafety.umn.edu/publications/researchreports/reportdetail.html?id=2784

CV PILOT TESTS AND DEMONSTRATIONS THAT INCLUDE WORK ZONE COMPONENTS

USDOT Wyoming Connected Vehicle Pilot Deployment

Entities Involved: USDOT ITS JPO, Wyoming DOT, University of Wyoming, Laramie County, multiple freight industry members, multiple consultants

Description of Effort: Wyoming is instrumenting 402 miles of Interstate 80 (I-80) across Wyoming by installing 75 Dedicated Short-Range Communications (DSRC) roadside units (RSUs) at priority locations (see Figure 4). Approximately 400 Wyoming DOT and commercial freight vehicles are being outfitted with on-board units (OBUs) to receive messages from the RSUs.



Source: Wyoming CV Pilot Factsheet (https://wydotcvp.wyoroad.info/assets/promotion/WyomingCVPilot_Factsheet_v2_020817.pdf)

Figure 4. Extent of the Wyoming CV Pilot.

Specific Work Zone Involvement: The Wyoming Connected Vehicle Pilot is implementing a work zone warning (WZW) application. The application will utilize available Traffic Information Message (TIM) work zone warning protocols for connected vehicles described in Society of Automotive Engineers (SAE) Standard J2735 (Section 6.142, part 3). Work zone information to be transmitted and received include obstructions in the travel lane, lane closures, lane shifts, speed reductions, and/or vehicles entering or exiting the work space.

Key Work Zone-Related Findings or Lessons Learned to Date: Work continues to evaluate the deployment at this time. Driver simulation research of the human-machine interface design for in-vehicle work zone warnings found a need to reduce the amount of information provided to not overload the driver approaching the work zone.

Contacts: Katherine Hartman, ITS JPO and Ali Ragan, Wyoming DOT
https://wydotcvp.wyoroad.info/

USDOT New York City Connected Vehicle Pilot Deployment

Entities Involved: USDOT ITS JPO; New York City DOT and Departments of Information Technology and Telecommunications, Sanitation, and Citywide Administrative Services; New York City Metropolitan Transportation Authority; Port Authority of New York/New Jersey; Pedestrians for Accessible and Safe Streets Coalition; and the Taxi and Limousine Commission.

Description of Effort: A connected vehicle system is being developed and implemented in specific East Side, Manhattan, and Brooklyn corridors (see Figure 5). Up to 8,000 fleet vehicles are being outfitted with OBUs, and approximately 300 RSUs are being installed at strategic locations (intersections, bus depots, river crossings, airports, etc.) to disseminate and receive real-time information using DSRC. Work continues to develop, deploy, and test the system with full operations scheduled to begin in September 2020.

Specific Work Zone Involvement: A compliance to the posted speed limit application is being developed to alert a driver when approaching a designated work zone or school zone that they are exceeding the speed limit for that location. For moving work zones, equipment installed on a barrier truck or other vehicle will mark the upstream end of the work zone and allow the system to provide location and speed zone warning information for the work zone. For longer work zones, a second vehicle may be similarly outfitted to disseminate the downstream geographic limit of the work zone.

Key Work Zone-Related Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Jonathan Walker, ITS JPO and Mohamad Talas, New York City DOT
https://www.cvp.nyc/

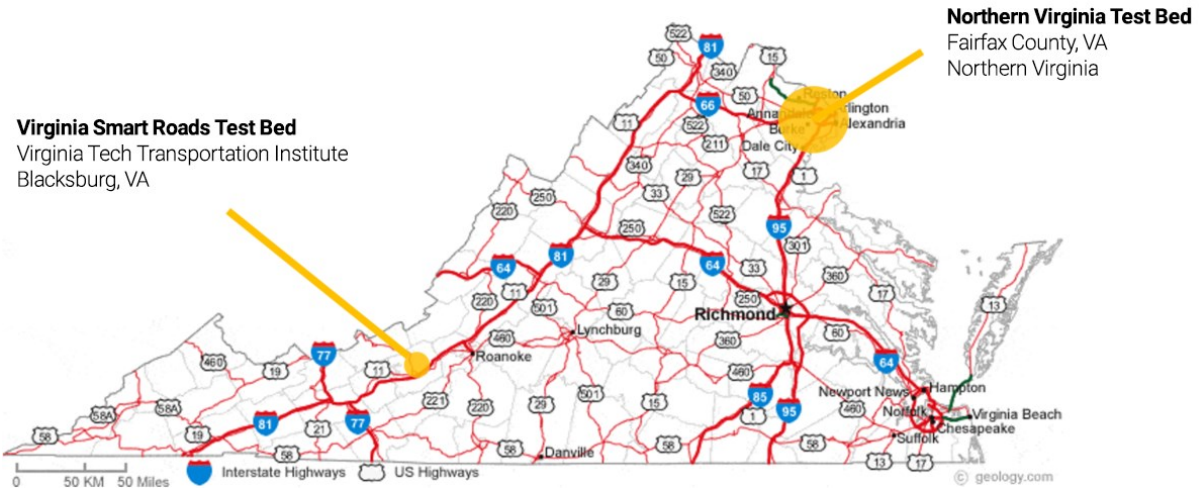
Source: NYC CV Project Scope (https://www.cvp.nyc/project-scope)

Figure 5. Extent of the New York City CV Pilot.

Virginia DOT Connected Corridors Initiative

Entities Involved: Virginia DOT, Virginia Tech Transportation Institute (VTTI), Virginia Transportation Research Council (VTRC)

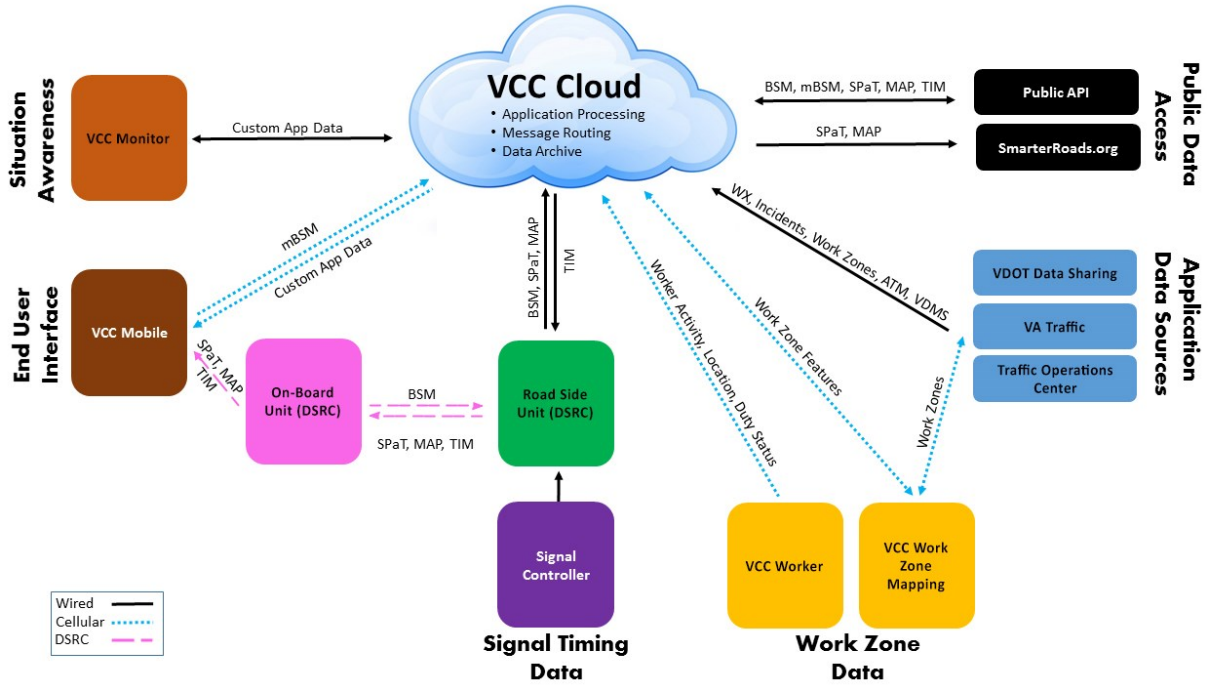
Description of Effort: The Virginia Connected Corridors (VCC) is a connected vehicle environment that is enabling the development and assessment of early stage connected and automated vehicle applications. Two locations make up the initiative (see Figure 6). The Northern Virginia Testbed consists of sections of interstates 66 and 495 (I-66 and I-495), US 29, and US 50. Meanwhile, the Virginia Smart Road, located in Blacksburg, is a closed-course setting that includes both controlled-access and surface street road segments.



Source: VCC Initiative Test Bed Locations (https://www.vtti.vt.edu/vcc/map.html).

Figure 6. Locations of the Virginia Connected Corridors Initiative.

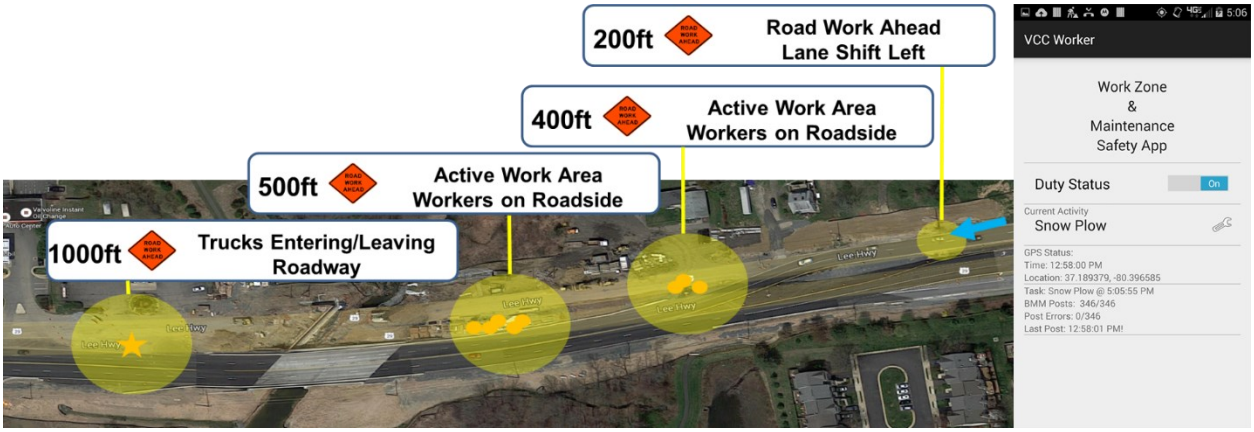
The VCC includes over 60 RSUs interacting with the VCC cloud that supports the management of connected vehicle messages between entities interacting on the VCC. A mobile application provides cellular connection to the VCC cloud, and 55 on-board units installed on Virginia DOT trucks and on private vehicles provide real-time communication between vehicles and with the connected infrastructure (see Figure 7).



Source: VTTI

Figure 7. The VCC Cloud.

Specific Work Zone Involvement: Work zone data are incorporated into the VCC via 1) a mobile VCC worker application that provides worker activity, location, and duty status (see Figure 8); and 2) a VCC work zone mapping application that captures various features of the work zone for incorporation into the cloud. The VCC cloud builds dynamic traveler messages about workers and work zones and pushes them to motorists on the VCC mobile app.



Source: VTTI

Figure 8. The VCC Worker application.

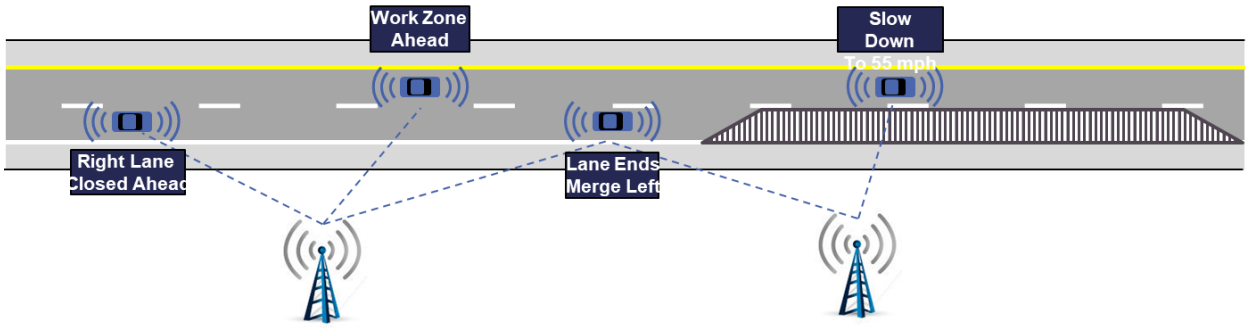
Key Work Zone-Related Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Mike Mollenhauer, VTTI
https://www.vtti.vt.edu/vcc/

FHWA/Texas DOT Connected Work Zone Initiative

Entities Involved: FHWA, Texas DOT, Texas A&M Transportation Institute (TTI), Southwest Research Institute (SwRI), Crash Avoidance Metrics Partners (CAMP), Lonestar Intelligent Transportation Systems

Description of Effort: FHWA and the Texas DOT entered into an agreement to enhance the I-35 Central Texas Traveler Information during Construction (TIDC) project to include commercial vehicle in-vehicle messaging. Information collected and computed regarding planned and current lane closures were used to support evolution and testing of the Freight Advanced Traveler Information Systems (FRATIS) concept, and to test the ability to create messages that support the Reduced Speed Zone Warning/Lane Closure (RSZW/LC) application dissemination via RSUs (see Figure 9).



Source: TTI

Figure 9. The Connected Work Zone Initiative.

Specific Work Zone Involvement: The project focuses specifically on the collection, dissemination, and use of work zone data for connected vehicle applications. FRATIS-involved efforts to provide freight drivers with departure time and route assistance have been completed and are documented at https://osadp.github.io/Construction-Work-Zone-Mitigation-Tool/. Work continues on testing RSUs in the corridor where ongoing construction is still occurring. Additional efforts on this project include the following:

- Developing connected work zone pathways to freight carriers
- Developing methods to incorporate connected work zone information into traveler information databases
- Using 3rd party crowdsourced data and connected work zone devices for queue detection and warning applications
- Testing and demonstration of connected worker technologies
- Dissemination of findings to accelerate national implementation

Key Work Zone-Related Findings or Lessons Learned to Date: Issues have arisen regarding a lack of interoperability between certain roadside units and on-board units. The need for a low-fidelity work zone mapping application was identified under the CAMP efforts on this project.

Contacts: Greg Davis, FHWA; Darius White, Texas DOT; Geza Pesti, TTI

Texas Connected Freight Corridors

Entities Involved: USDOT, Texas DOT, TTI, SwRI, University of Texas, various private-sector companies

Description of Effort: The Texas Connected Freight Corridors project is Texas' largest deployment of connected vehicle (CV) technology aimed at making a significant reduction in the number and severity of crashes, reducing congestion on major interstates that serve the nation, and reducing fuel consumption of freight trucks. As a U.S. Department of Transportation (US

DOT) Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) award, the Texas Connected Freight Corridors project is applying advanced safety and congestion management technologies to improve traveler information, asset condition assessment, and system performance. The effort focuses on the 865-mile Texas "triangle" that connects Houston, Dallas, and San Antonio via Interstates 10, 30, 3, and 45 (see Figure 10).

Specific Work Zone Involvement: Providing work zone information and work zone alerts to freight operators is one of the components being incorporated into the project.

Key Work Zone Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Jianming Ma, Texas DOT; Nick Wood and Ed Seymour, TTI

Source: Texas DOT

Figure 10. The connected freight corridors project focuses on interstates connecting the Texas triangle.

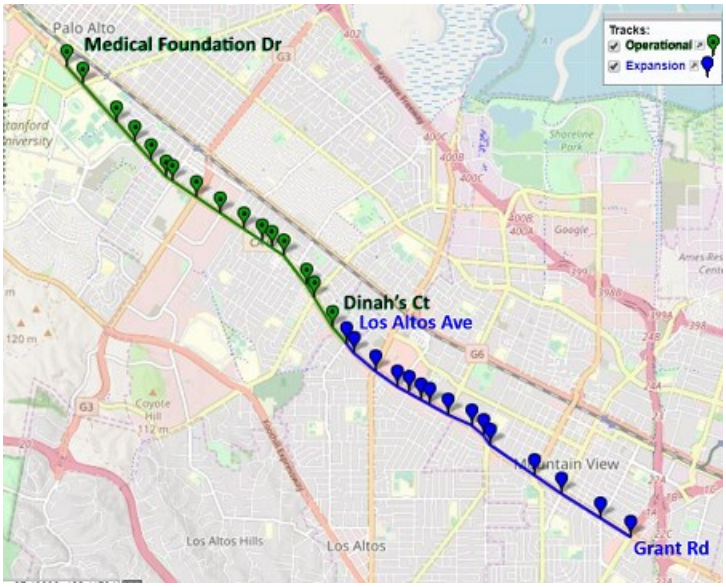
California CV Testbed

Entities Involved: California Department of Transportation (CALTRANS), Metropolitan Transportation Commission (MTC), and the California PATH program at UC Berkeley

Description of Effort: A CV testbed has been created on El Camino Real (State Route 82), a signalized arterial roadway that serves more than 50,000 vehicles traveling each day between San Francisco and San Jose (see Figure 11). Work is now underway to expand its size from the original 11 intersections to 31 intersections between Medical Foundation Dr. in Palo Alto and

Grant Rd in Mountain View. Caltrans is working with PATH and ProspectSV to ensure that the Test Bed is available to all developers to test how connected vehicle technologies perform under real-world conditions.

Specific Work Zone Involvement: Researchers have demonstrated the ability to broadcast a work zone lane closure and reduced speed limit roadway safety message (RSM) at one of the intersections in the testbed based on the CAMP RSM format. Both visual and audio advance warnings of a virtual work zone lane closure have been successfully broadcast via RSUs to a test vehicle with an OBU.



Source: CA CV testbed
(http://www.caconnectedvehicletestbed.org/index.php/index.php)

Figure 11. Extent of California CV testbed.

Key Work Zone-Related Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Kun Zhou, California PATH
https://caconnectedvehicletestbed.org.

Modernize 75

Entities Involved: Michigan DOT

Description of Effort: A 15-mile I-75 corridor north of Detroit has been outfitted with permanent and portable connected vehicle infrastructure to allow Traveler Information Messages (TIM) to

be disseminated to connected vehicles and to receive, collect, and stream basic safety messages (BSM) from connected vehicles to a central location.

Specific Work Zone Involvement: The system disseminates information regarding lane closures, divided lane advisories, speed limit notices, exit ramp closure statuses, and traffic shift notifications.

Key Findings or Lessons Learned to Date: The project is still in progress.

Contact: https://www.modernize75.com/find-information/contact-us/

EFFORTS TO SUPPORT AUTOMATED DRIVING SYSTEM ACCOMMODATION OF WORK ZONES

Safe Integration of Automated Vehicles into Work Zones

Entities Involved: USDOT, Pennsylvania DOT, Pennsylvania Turnpike, Penn State University, Carnegie-Mellon University, multiple consultants, industry partners

Description of Effort: This consortium was awarded a four-year Automated Driving System (ADS) demonstration grant to study the impact of improved connectivity between AVs and work zone features, improvements in pavement marking materials upon machine vision used by AVs, improved high-definition mapping of work zone features, and improved map information dissemination to the AVs by map providers and/or infrastructure owner/operators.

Specific Work Zone Involvement: The consortium is examining up to 17 different work zone scenarios using simulation and closed-course testing, deployment, and evaluation of AVs operating at SAE Level 4 with and without connectivity between vehicles and with the infrastructure. These scenarios are based on the typical applications found in the MUTCD and/or the Pennsylvania DOT typical application drawings for mobile, short-term, and long-term work operations on conventional highways and freeways/expressways (see Table 2).

Key Work Zone-Related Findings or Lessons Learned to Date: The project was awarded in Fall 2019.

Contacts: Mark Kopko, Pennsylvania DOT
https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/351461/36-penndot.pdf

Table 2. Work Zone Scenarios Being Examined.

Roadway Type	Work Duration	Work Zone Scenario
Conventional Highways	Short-Term	Work space on or beyond shoulder
		Road closure with detour
		Work space in the single-lane approach
		Single-lane closure; traffic shifted into two-way left-turn lane
		Work space in the two-way left-turn lane
		Work space in the left or right lane of a two-lane approach
	Long-Term	Detour of a numbered traffic route
		Self-regulating stop sign-controlled lane closure
		Temporary roadway
		Complex condition; trailer-mounted signals
	Mobile	Moving lane closure
Freeways and Expressways	Short-Term	Work space in the left or right lane of a two-lane approach
		Lane closure near a freeway or expressway exit ramp
		Lane closure near a freeway or expressway entrance ramp
	Mobile	Work space in the left or right lane
		Work space in any lane of a three- or more-lane approach
	Other	Freeways and expressways - long-term shoulder lane use

Source: Safe Integration of Automated Vehicles into Work Zones grant application, Pennsylvania DOT

Cooperative Automation Research Mobility Application (CARMA)

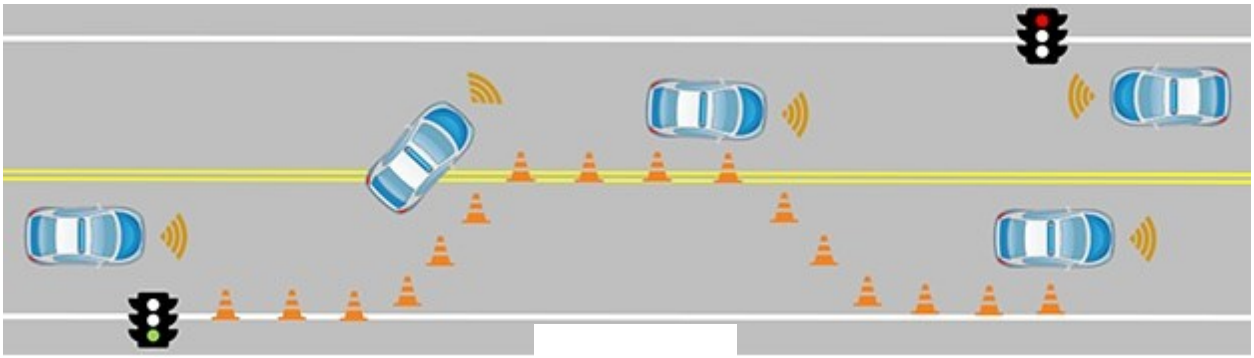
Entities Involved: FHWA, various consultants, public- and private-sector collaborators

Description of Effort: CARMA is an open-source software platform designed to enable the testing and evaluation of cooperative automation concepts for improving safety and increasing infrastructure efficiency and interoperability. The third version, CARMA3, is under development to support application development and communications between cloud services and vehicles, infrastructure, and other road users.

Specific Work Zone Involvement: Work is underway to develop new applications that use cooperative-automated driving systems to support traditional transportation systems management and operations. Work zone management is one of the applications now receiving attention. Specific situations being considered include:

- Notify travelers of upcoming work zone
- Detect unplanned utility work
- Detect and react to a work zone queue
- Merge at a work zone
- Stage work vehicles in a work zone (construction vehicles entering and exiting at access points)

- Alternating one-way operations on a two-lane roadway (see Figure 12)
- Clear and terminate a work zone



Source: FHWA

Figure 12. Illustration of an alternating one-way operation work zone being examined in CARMA.

Work is also underway to demonstrate the feasibility of using data from vehicle-based sensors for automatically identifying and mapping work zone geographic information.

Key Work Zone-Related Findings or Lessons Learned to Date: Work continues in developing work zone management situations and mapping demonstration.

Contacts: Taylor Lochrane, FHWA
https://highways.dot.gov/research/operations/Cooperative-Driving-Automation

EFFORTS TO UTILIZE ADVANCED TECHNOLOGIES TO IMPROVE WORKER SAFETY IN WORK ZONES

Design and Evaluation of a Connected Work Zone Hazard Detection and Communication System for Connected and Automated Vehicles

Entities Involved: VTTI, SAFE-D University Transportation Center

Description of Effort: Researchers investigated the potential ultra-wide band (UWB) technology for reliable localization and mapping of roadside work zone workers in real-world environments. If feasible, such information could then be shared with connected and automated vehicle applications to improve safety.

Specific Work Zone Involvement: The project was completely work zone focused.

Key Work Zone-Related Findings or Lessons Learned to Date: A final report on this effort is available. Researchers determined that UWB technology would not be suitable for localizing and mapping of workers. A specification for a wearable vest that would serve localization and mapping purposes was developed for use in future research.

Contacts: Michael Mollenhauer, VTTI
https://vtechworks.lib.vt.edu/handle/10919/95180

Implementation and Assessment of Work Zone Intrusion Technologies

Entities Involved: Indiana DOT, Purdue University

Description of Effort: To assist the Indiana DOT (INDOT) with enhancing the safety of motorists and workers in construction work zones on high-speed roadways, this study aims to provide INDOT work zone safety committee with guidance on selection, assessment, and implementation of work zone intrusion technologies. The proposed research will include comprehensive and accurate information about innovative technologies to improve safety in work zones (guidebook, training, and strategies).

Specific Work Zone Involvement: The project is completely work zone focused.

Key Work Zone-Related Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Sogand Hasanzadeh, Purdue University

Work Zone Intrusion Alert System Technology Tests

Entities Involved: North Carolina DOT, East Carolina University

Description of Effort: This study will evaluate the effectiveness of the work zone intrusion detection and alert system prototype that was developed by the principal investigator. Research will include intrusion experiments to measure the effectiveness of the intrusion detection and timely activation and the dissemination of the alerts; the observation of the utilization of the device by the study participants (e.g., workers, field engineers) to evaluate the usefulness of the system to be used in actual work areas; and 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).

Specific Work Zone Involvement: The project is completely work zone focused.

Key Work Zone-Related Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Erol Ozan, East Carolina University

Alternative Technologies for Mitigating the Risk of Injuries and Deaths in Work Zones

Entities Involved: Oregon State University

Description of Effort: The objective of this project is to provide guidelines on use of work zone intrusion mitigation technologies by (1) identifying successful applications of emerging technologies to mitigate work zone intrusions; and (2) developing a technology implementation guidebook that helps transportation agencies select and implement emerging technologies to prevent work zone intrusions, and ultimately improve work zone safety.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Work Zone-Related Findings or Lessons Learned to Date: The final report for the project is being reviewed.

Contacts: John Gambatese, Oregon State University
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4491

Development of a Roadside LiDAR-Based Situational Awareness System for Work Zone Safety: Proof-of-Concept Study

Entities Involved: TTI, SAFE-D University Transportation Center

Description of Effort: This project utilizing lightweight portable 360° LiDAR sensors at the roadside to test their potential for providing work zone safety in terms of accuracy, efficiency, and ease of use. The objective is to develop a set of algorithms to collect and interpret real-time information of each approaching vehicle and worker (e.g., location, speed and direction) in and outside work zones using the roadside LiDAR sensing equipment. Ultimately, the outcome of this study will produce a full-scale warning system that is deployable in a real work zone environment. Such a system can detect and analyze live traffic and work zone activity, activate the appropriate warning scheme, and deliver information to roadway workers in work zones so that they can take evasive actions instead of passively relying on traditional safety countermeasures.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Work Zone-Related Findings or Lessons Learned to Date: The project is still in progress.

Contact: Jason Wu, TTI
https://safed.vtti.vt.edu/projects/development-of-a-roadside-lidar-based-situational-awareness-system-for-work-zone-safety-proof-of-concept-study/

User-Centered Smart Traffic Sign Development Study

Entities Involved: Minnesota Local Road Research Board, Minnesota DOT, University of Minnesota

Description of Effort: This project proposes to develop a smart traffic sign device using low-cost sensors that can automatically detect potential intruding vehicles and provide an audio-visual alert to warn both the driver and workers of the impending event during flagging operations. For success of such a system, it is critical that the design team take a human-centered approach to fully account for the needs and demands of flaggers and design the system in partnership with workers.

Specific Work Zone Involvement: This project is completely work zone focused.

Key Work Zone-Related Findings or Lessons Learned to Date: The project is still in progress.

Contacts:
Nicole Morris, University of Minnesota
https://www.cts.umn.edu/research/project/user-centered-smart-traffic-sign-development-study

Development of a Connected Smart Vest for Improved Roadside Work Zone Safety

Entities Involved: VTTI, SAFE-D University Transportation Center

Description of Effort: The focus of this project is to develop a wearable worker localization and communication device (i.e., Smart Vest) that utilizes a previously developed Threat Detection Algorithm to communicate workers' locations to passing CVs and AVs and proactively warn workers and passing motorists of potential collisions.

Specific Work Zone Involvement: The target group for this research are workers who are on foot in and around the work zone. The system monitors worker locations and compares that information to connected vehicle trajectories and other data to assess potential threats of vehicle-worker collisions in real-time.

Key Work Zone-Related Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Nazilla Roofigari-Esfahan, VTTI
https://www.vtti.vt.edu/utc/safe-d/index.php/projects/development-of-a-connected-smart-vest-for-improved-roadside-work-zone-safety/

Smart Work Zone System

Entities Involved: VTTI, SAFE-D University Transportation Center

Description of Effort: To support the connected smart vest described in the previous project, a base-station is being added that provides an edge computing environment for alert algorithm processing, consolidates communications of individual worker positions via a 4G link to a cloud computing environment, and can be coupled with a local RSU to support the broadcast of work zone information to connected vehicles. In addition, a smart cone device is being added that can help automatically define safe area boundaries and improve communications reliability between workers and the base station. The entire package is being developed to support a broader scale deployment of the technology with the Virginia Department of Transportation.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Work-Zone Findings or Lessons Learned to Date: The project is still in progress.

Contacts:
Mike Mollenhauer, VTTI
https://safed.vtti.vt.edu/projects/smart-work-zone-system%e2%80%8b/

A Smart IoT Proximity Alert System for Highway Work Zone Safety

Entities Involved: Georgia Institute of Technology (NCHRP-IDEA project)

Description of Effort: This project will develop and validate a smart IoT proximity alert system for proactive safety warning at dynamic roadway work zones. Work in Stage 1 will focus on developing and prototyping the proposed system. Both personal and equipment protection units (PPUs and EPUs) will be developed by designing a printed circuit board (PCB) in a small form so that it could be converted to a wristwatch or attached to a safety vest to increase workers' alert perception. Workers' feedback will be used to evaluate PPU performance. A mesh network with no single point of failure, simple connectivity, and low power will be developed and investigated in the prototyping stage for an efficient management of the tradeoffs between power consumption and network connectivity. A cloud server system will be developed to collect incident data (e.g., near misses) detected by the PPUs and EPUs. The data will be transferred to the server system from EPUs via the mesh network. The server system will monitor each PPU and EPU, and data analysis reports will be generated from the web server's interface. In Stage 2, the prototype system will be tested under various real-world field conditions to validate its effectiveness. These tests will be conducted in collaboration with Georgia DOT's construction and maintenance groups, equipment manufacturers, and general contractors.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Work-Zone Findings or Lessons Learned to Date: The project is still in progress.

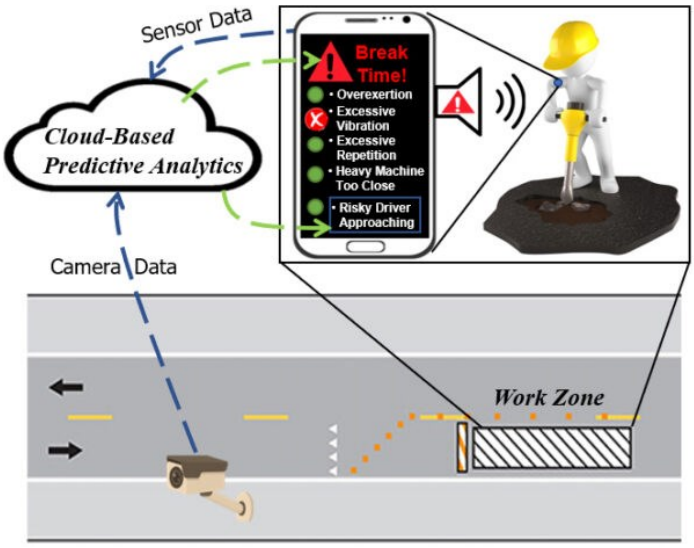
Contacts: Yong Cho, Georgia Institute of Technology
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5060

A Holistic Work Zone Safety Alert System through Automated Video and Smartphone Sensor Data Analysis

Entities Involved: San Diego State University, SAFE-D University Transportation Center

Description of Effort: This project presents a hybrid approach in which visual- and wearable-sensor data are used for safety monitoring and alert generation to offer a practical mitigation

strategy to both external and internal safety risks. It leverages smartphones as a pervasive and standalone resource for collecting data and communicating safety-related instructions to workers (see Figure 13). The project also uses information systems and behavioral science theories (i.e., technology acceptance model and Diffusion of Innovation theory) to build end-users trust toward scalable adoption of the developed systems.



Source: SAFE-D University Transportation Center

Figure 13. Illustration of smartphone data collection and communication tool in work zones.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Work-Zone Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Reza Akhavian, San Diego State University
https://safed.vtti.vt.edu/projects/a-holistic-work-zone-safety-alert-system-through-automated-video-and-smartphone-sensor-data-analysis/

From Location Tracking to Continuous Interpretation: Rule-Based Automated Safety Work Zone Safety

Entities Involved: University of Houston, University of Nebraska (NCHRP-IDEA project)

Description of Effort: The focus of this project is to deliver, develop, and test an automated safety monitoring system using UWB sensing of both workers and equipment, and innovative rule-based software to identify and prevent potential hazards and conflicts. All system components -- location tracking, rule-based software program, alerting devices and a tablet application -- will be integrated in a cloud-based platform.

Specific Work Zone Involvement: The emphasis of this project is on monitoring interactions between workers and work equipment within the work space. The software user interface will support the creation of objects and information in Internal Traffic Control Planning.

Key Work Zone-Related Findings or Lessons Learned to Date: The final report for the project is currently being prepared.

Contacts: Kyungki Kim, University of Nebraska

Development, Education, and Implementation of A Low-Cost Audio Sensor-Based Autonomous Surveillance System for Smart and Connected Transportation Infrastructure Construction and Maintenance

Entities Involved: Louisiana State University (LSU), Transportation Consortium of South-Central States

Description of Effort: This project is examining a new approach for low-cost audio sensor-based autonomous site and safety surveillance of transportation construction and maintenance work. A low-cost wearable audio sensor will be created for monitoring and activity log generation. A sound-based site and safety monitoring framework supports an unlimited range of monitoring angles and illumination levels with lightweight data processing and comparatively quick analytics.

Specific Work Zone Involvement: The emphasis of this project is on monitoring interactions between workers and equipment in the work space. The project includes algorithm development to identify potential safety conflicts between them so that workers can be warned before an accident occurs.

Key Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Yong-Cheol Lee and Jin-Woo Choi, LSU
https://transet.lsu.edu/wp-content/uploads/sites/16/2019/08/19PPLSU12-PIF.pdf

Autonomous Maintenance Technology (AMT) Pooled Fund Study

Entities Involved: Colorado DOT (Lead), 11 other state DOTs

Description of Effort: A pooled-fund study has been established to conduct research on AMT, focusing on automated truck-mounted attenuator (ATMA), sometimes referred to as automated impact protection vehicle (AIPV) platforms. Research efforts focus on improvements to existing ATMA/AIPV platforms, expansion of uses of this technology, refining policy, defining operational procedures for autonomous work vehicles in general, and exploration of new technologies.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Findings or Lessons Learned to Date: The following activities have been completed or are underway:

- Evaluating the Human-Automated Maintenance Vehicle for Improved Safety and Facilitating Long Term Trust.
- Development of ATMA/AIPV Deployment Guidelines Considering Traffic and Safety Impacts
- ATMA Tabletop (All Clear Emergency Management)
- ATMA Cybersecurity Complement
- ATMA Documentation
- ATMA Incident Form Workshop (All Clear Emergency Management)
- ATMA Cost-Benefits
- Literature Review Synthesizing the current and Potential ATMA Applications (
- Impact Performance of Autonomous Impact Protection Vehicle (AIPV) with Truck Mounted Attenuator
- Building Cloud Based Interactive Data Visualization
- Risk Assessment for Operational Safety of ATMA

Contacts: David Reeves, Colorado DOT
http://www.csits.colostate.edu/autonomous-maintenance-technology.html
https://www.codot.gov/programs/research/pdfs/2021/2021-05.pdf
https://www.codot.gov/programs/research/pdfs/2021/cdot202109atma-tabletopexercise.pdf

Implementation Exploration of Autonomous Vehicles: Impacts of Autonomous Truck-Mounted Attenuator (ATMA) on Indiana DOT (INDOT) Work Zone Safety, Mobility, and Crews' Perception/Behavior/ Productivity

Entities Involved: Indiana DOT, Purdue University

Description of Effort: Utilization of ATMAs is believed to protect crews and drivers from crashes caused by reckless and distracted drivers. This study will develop a tailored ATMA plan based on observations from existing TMA operations, INDOT crews' perception of ATMA and characteristics of ATMA's operation environment in Indiana. The project will evaluate the ATMA in field tests and provide recommendations for implementation.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Findings or Lessons Learned to Date: The project is still in progress

Contacts: Yunfeng Chen, Jiansong Zhang, and Yiheng Feng, Purdue University

Automated Truck Mounted Attenuator

Entities Involved: VTTI, SAFE-D University Transportation Center

Description of Effort: This project focuses on developing an ATMA/AIPV. The proposed system will utilize a short-following distance, leader-follower control concept so that a driver is not needed in the at-risk trailing truck-mounted attenuator/advance impact protection vehicle.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Mike Mollenhauer, VTTI
https://www.vtti.vt.edu/utc/safe-d/index.php/projects/automated-truck-mounted-attenuator/

OTHER INITIATIVES

Preparing Work Zones for Automated and Connected Vehicles

Entities Involved TTI, SAFE-D University Transportation Center

Description of Effort: To accelerate the adoption of advanced vehicle technology nationwide, work zone practitioners will need to identify ways in which they can better plan, design, and implement work zones to support current and future vehicles. This project will examine how transportation agencies, contractors, and other stakeholders can best plan, design, and implement work zones to accommodate and support CV and AV operations. Under this project, researchers are examining the information/data requirements that CVs and AVs will likely have to operate through work zones, impediments to providing that data, potential benefits of providing that data, possible implementation approaches, and needed research efforts and outcomes needed to accomplish that implementation.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Gerald Ullman, TTI
https://www.vtti.vt.edu/utc/safe-d/index.php/projects/preparing-work-zones-for-automated-and-connected-vehicles/

Preparing Transportation Agencies for Connected and Automated Vehicles in Work Zones

Entities Involved: VTTI

Description of Effort: To help transportation agencies prepare for connected and automated vehicles in work zones, the objectives of this project are to:

- Identify technical needs and potential impacts of CVs and AVs in work zones.
- Document deployed and planned practices for CVs and AVs in work zones.
- Evaluate the qualitative and quantitative benefits of these practices, e.g., return on investment and improved safety, mobility, and user/worker awareness.
- Identify research needed for addressing gaps in implementing various CV/AV practices.
- Educate stakeholders on research findings through webinars and other materials.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Luke Neurauter, VTTI
https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4865

Modern Solutions to Safe and Efficient Work Zone Travel

Entities Involved: VTTI

Description of Effort: The objectives of this research are to: (1) evaluate innovative and adaptive technologies that are attention-capturing and enhance work zone safety and mobility; (2) evaluate the use of crowdsourcing applications and data analytics for dynamic work zone devices and in-vehicle notifications for traffic management; and (3) develop a guide for the application and management of innovative work zone technologies.

Specific Work Zone Involvement: The project is completely work zone focused.

Key Findings or Lessons Learned to Date: The project is still in progress.

Contacts: Mike Mollenhauer, VTTI
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4963

Implementation of Enhanced Probe Data (CANBUS) for Tactical Workzone and Winter Operations Management

Entities Involved: Purdue University, Indiana DOT

Description of Effort: This project is incorporating connected vehicle data (hard braking events) into weekly work zone reports to provide Indiana DOT with an assessment of their queue warning systems and improved hazard detection. Traction control and anti-lock braking events are being integrated into the winter operations traffic ticker and after-action reports during winter months.

Specific Work Zone Involvement: Connected vehicle hard braking events are being used to identify potential work zone hazard locations. Changes in hard braking events upstream of work zone-induced traffic queues are being used to evaluate queue warning technology.

Key Findings or Lessons Learned to Date: Effectiveness of queue warning technologies have been demonstrated through reductions in hard braking frequency upstream of queues.

Contacts: Darcy Bullock, Purdue University