PI-0364 - Automated Connected Technologies (ACT) and Remote Virtual Inspection (RVI) for Work Zones

Requested by
Division of Construction

Prepared by
Colman Cronin, PE, Senior Transportation Engineer, DRISI

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The Caltrans Division of Research, Innovation and System Information (DRISI) receives and evaluates numerous research problem statements for funding every year. DRISI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field. The contents of this document reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the California Department of Transportation, the State of California, or the Federal Highway Administration. This document does not constitute a standard, specification, or regulation. No part of this publication should be construed as an endorsement for a commercial product, manufacturer, contractor, or consultant. Any trade names or photos of commercial products appearing in this publication are for clarity only.

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Executive Summary

Background

The following background discussion was extracted from the research problem statement provided by the Institute for Transportation, Iowa State University.
The application of Automated Connected Technologies (ACT) has shown promise in not only improving safety and awareness in highway work zones, but also has demonstrated effectiveness in improving the efficiency of DOT field staff. Delaware DOT has used its Federal Highway Administration (FHWA) Advanced Digital Construction Management System (ADCMS) grant to demonstrate the capability of connecting construction equipment telematics with automated work zone informational alerts to the traveling public about work zone activity. The project has also demonstrated the use of ACT to assist field staff in preparing work reports and project records. The delivery of materials and connections to equipment informs the connected system about the work being done and the materials being delivered. The addition of other data sources, such as local weather, allows ACT to provide a draft of daily work reports or other project documentation. Field staff then only need to adjust these reports, reducing the time needed to manually create the full report.

Additionally, Remote Virtual Inspection (RVI) technologies allow for the inspection of transportation construction projects in a safe and virtual setting. Advanced and emerging digital technologies have made it possible to perform RVI for tasks such as measuring and verifying quantities, bridge inspection from a distance, monitoring construction progress, tracking materials and inventory, measuring material strengths, locating underground assets, creating as-builts, and monitoring environmental impact.

Problem Statement

The following problem statement was extracted from the research problem statement provided by the Institute for Transportation, Iowa State University.
Highway construction and maintenance workers face unique hazards as the work is conducted in locations adjacent to high-speed traffic, from heights or over water, around large construction and maintenance equipment loading and hauling massive amounts of materials, and in extreme environmental conditions. These hazards resulted in 135 worker fatalities within highway work zones in 2019, which was up from 124 in 2018 (National Work Zone Safety, 2019). Worker fatalities resulting from workers being struck by non-work vehicles have not decreased overall in recent years, with 159 worker fatalities in 2020, 163 in 2021, and 138 in 2022 (FARS, 2024).

Summary of Findings

The primary objective of the research project proposed by the Institute for Transportation, Iowa State University is to develop guidance for implementing ACT and RVI technologies to improve construction and maintenance work zone safety with an evaluation of the effectiveness of these approaches. This In-House Preliminary Investigation was conducted to ascertain whether credible national work on the scope of the research proposal has already been completed or is currently in progress.

The website titled "Work Zone Safety Information Clearinghouse" provides some of the most up-to-date information on efforts by States to implement research and pilot projects on the use of autonomous and connected technologies in highway work zones. It provides webinars and case studies from different states to showcase the following types of Smart Work Zone (SMZ) technology applications:

- Real Time Traveler Information
- Queue Warning
- Dynamic Lane Merge
- Incident Management
- Variable Speed Limit
- Speed Safety Cameras
- Entering/Exit Vehicle Notification
- Connected Vehicles (CV) and Automated Vehicles (AV) Operations in Work Zones

NCHRP Synthesis 587 titled "Use of Smart Work Zone Technologies for Improving Work Zone Safety" (2022) provides a comprehensive review of the use of smart work zone technologies for improving work zone safety. The report includes a literature review and case studies from seven states. In addition, NCHRP Web-Only Document 322 titled "Alternative Technologies for Mitigating the Risk of Injuries and Deaths in Work Zones: Conduct of Research" (2022) provides a comprehensive synthesis and evaluation of technologies that prevent and/or mitigate intrusions into work zones. The technologies are predominately categorized into following types:

- Motorist vehicle systems (like connected and automated vehicles or CAVs)
- Construction equipment systems
- Unmanned aerial system (UAS)
- Intrusion detection and alerts
- Enhanced signage and enforcement
- Wearables

In the research area of Remote Virtual Inspection (RVI) technologies, NCHRP Synthesis 582 titled "Highway Infrastructure Inspection Practices for the Digital Age" (2022) categorizes RVI technologies as follows:

Geospatial Technologies

- Global Navigation Satellite Systems (GNSS)/Global Positioning System (GPS)
- Geographic Information Systems (GIS)
- Unmanned aircraft systems (UASs)
- Robotic total stations (RTSs)
- Terrestrial photogrammetry (TP)
- E-ticketing

Remote Sensing and Monitoring Technologies

- Light imaging, Detection, and Ranging (LiDAR)
- As-built and maintenance documentation—The data are integrated into a centralized database that is continuously updated for future planning, maintenance, and construction.
- Pavement smoothness and quality determination—Data collected at higher resolutions can be used to evaluate pavement smoothness and quality.
- Construction automation and quality control—Change detection and deviation analysis software uses design models to identify deviations from LiDAR point clouds for construction quality control.
- Performing quantity takeoff—LiDAR data are used to determine lengths, areas, or volumes of construction quantity.
- Virtual and 3D design—LiDAR data can be used for clash detection by checking for intersections of proposed objects with existing objects modeled in the point cloud.
- Inspections—LiDAR can provide overall geometric information and an overall condition assessment.

Radio-Frequency Identification
Intelligent Compaction
Barcodes
Mobile Devices and Software Applications

- 3D Engineered Models (BIM)
- Automated machine guidance (AMG)
- Handheld devices

Virtual reality (VR) and Augmented Reality (AR)
Nondestructive testing (NDT) technologies

- Ground-penetrating radar (GPR)
- Infrared Thermal Profilers

Caltrans implemented technologies at the intersection of ACT and RVI as part of the Ferguson Rock Shed Project on Route 140 in Mariposa County in District 10. Several technologies were used to ensure the safety of personnel at the work site. To overcome the safety challenge of working in an active landslide with falling rocks, Caltrans required the use of remote-controlled excavating and earth-moving equipment. In addition, radar-based remote monitoring equipment was used to monitor the movement

of the slide. The project is scheduled to begin construction of the 675 feet long rock shed in the summer of 2025. The rock shed will be segmentally constructed by hydraulically launching the precast segments along a curve. Further details of the project can be found at the following link:

https://dot.ca.gov/caltrans-near-me/district-10/district-10-current-projects/ferguson-slide-project

DRISI has not recently funded research studies on highway construction work zones, however, findings from other recent research projects related to maintenance activities on the highway could inform studies on the mitigation of risks in construction work zones. Some examples are studies that evaluated work zone intrusions alarms, wrong way driving detection technologies and targeted warning messages to protect moving and stationary maintenance lane closures. Other recent research funded by DRISI looked more generally at the implications and implementation of Connected Vehicles (CV) and Autonomous Vehicles (AV) with highway traffic. Earlier research projects did study work zones through the lens of data collection and assessment of speed reduction countermeasures.

Preliminary Investigations into activities in highway construction work zones also focused on safety countermeasures and risk mitigation, including advance warning signs, barriers, intrusion alarms and safety policies and procedures for the work zone. The 2021 Preliminary Investigation (PI-0296) titled "Work Zone Safety: Synthesis of Literature and Industry Survey" sought information about recently developed safety innovations that alert workers and drivers in work zones and an online survey gathered information from manufacturers and vendors that provide work zone-related safety products and systems.

DRISI has not funded research projects that studied RVI technologies directly related to highway construction work zones. A 2021 Preliminary Investigation did study the feasibility of utilizing automated LiDAR extraction software for feature extraction.

Gaps in Findings

This Preliminary Investigation conducted a cursory review of Final Reports related to Automated Connected Technologies (ACT) and Remote Virtual Inspection (RVI) technologies through internet searches primarily available in the DRISI and Transportation Review Board (TRB) databases (e.g., NCHRP). An in-depth search of engineering journals was not conducted, which may be considered a gap in the findings. However, the journal papers that appeared in general internet searches (e.g., Google, Bing) were too narrowly focused to be practically informative for the research goals. A State-of-the-Art national survey of State Departments of Transportation was not considered for this Preliminary Investigation because this type of survey was partially completed in some of the NCHRP syntheses, and a complete survey is proposed as part of Task 1 of the research problem statement provided by the Institute for Transportation, Iowa State University as noted in Next Steps below.

Next Steps

The following proposed methodology for further research was extracted from the research problem statement provided by the Institute for Transportation, Iowa State University:

Phase I of the research will include a review of the literature to identify strategies/technologies that document the use cases of -

- Connected technologies to automate data flow, safety feeds, and work zone advisories,
- Remote virtual inspection,
- Automated documentation of highway construction or maintenance operations
- Eliminated or minimized DOT staff risk exposure in bridge and highway construction and maintenance operations.

- A nationwide survey to determine strategies/technologies for the above purposes.

Phase II of the research will:

Host a workshop to discuss agency experience with, or interest in, the identified strategies/technologies,

Develop guidance, prioritization, and piloting efforts to advance the technological capabilities of Caltrans in use of RVI and ACT.

Phase III will implement RVI and ACT in Caltrans pilot projects.

Phase IV will involve data collection (such as traffic speeds and crash data) and evaluation of the pilot projects to determine the effectiveness of RVI and ACT applications.

Detailed Findings

This Preliminary Investigation conducted a cursory review of Final Reports related to Automated Connected Technologies (ACT) and Remote Virtual Inspection (RVI) technologies through internet searches primarily available in the DRISI and Transportation Review Board (TRB) databases (e.g., NCHRP). The reports are listed below with hyperlinks. Abstracts are also provided for the reports believed by the author to be most relevant to the objective/goals of this preliminary investigations study.

Transportation Research Board (TRB) Publications

TRB – New, Pending and In-Progress research related to ACT & RVI

NCHRP 10-112 [Active] - Guide for Remote Virtual Inspection for Highway Construction Infrastructure Projects
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=5144

NCHRP 20-102 [Active] - Impacts of Connected Vehicles and Automated Vehicles on State and Local Transportation Agencies--Task-Order Support
http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3824

NCHRP Research Report 1142 Pre-Publication Draft—Innovative Approaches to Enhancing Safety and Efficiency in Work Zones: A Guide (2024)
http://nap.nationalacademies.org/28850

NCHRP Syntheses and Final Reports

NCHRP Synthesis 587: Use of Smart Work Zone Technologies for Improving Work Zone Safety, 2022
https://nap.nationalacademies.org/catalog/26637

NCHRP Synthesis 582: Highway Infrastructure Inspection Practices for the Digital Age, 2022
http://nap.nationalacademies.org/26592

NCHRP Web-Only Document 322 - Alternative Technologies for Mitigating the Risk of Injuries and Deaths in Work Zones: Conduct of Research, 2022
http://nap.nationalacademies.org/26626

NCHRP Report 1003 - Guide to Alternative Technologies for Preventing and Mitigating Vehicle Intrusions into Highway Work Zones , 2022
http://nap.nationalacademies.org/26625

NCHRP Synthesis 591: Use of Safety Management Systems in Managing Highway Maintenance Worker Safety, 2022
http://nap.nationalacademies.org/26672

NCHRP Domestic Scan 22-02 - Experiences in the Use of Digital Construction Management in the Highway Industry
https://www.trb.org/NCHRP/USDomesticScanProgram.aspx

DRISI Project Final Reports

Final Reports for DRISI funded research with material related to ACT and RVI are listed below.

DRISI Project Final Reports (2019 – 2024)

Pilot Testing of Work Zone Intrusion Alarms (Task 3875) – Final Report – November 2024 – Ghazan Khan, Raven Cochrane, Kevan Shafizadeh - California State University, Sacramento

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/evaluation-of-wzia-3875-final-report-v4-a11y.pdf

From the abstract: The main goal for this research was to evaluate the effectiveness and practicality of deploying and operating selected WZIA systems in California work zones. The objective was to provide recommendations and guidance to Caltrans on implementing such systems in real-world conditions through field observations and feedback provided by the Caltrans maintenance staff. Selected WZIA systems were procured and tested in active work zone conditions after two crews of Caltrans maintenance workers were provided an opportunity to train with the systems. Worker feedback on the performance and effectiveness of the systems was collected before and after testing in active work zone conditions. The selected WZIA systems were tested in a variety of active work zone conditions to ascertain their capabilities and practicality related to deployment, operation, retrieval, and overall effectiveness in improving work zone safety, while considering potential for worker exposure to traffic during deployment and operation besides other practical considerations. Based on the outcomes of this research, some general guidance and recommendations related to the use of WZIA systems were also developed that can highlight and ensure best practices for future use and implementation of WZIA systems.

Targeted Warning Messages to Protect Moving and Stationary Maintenance Lane Closures (Task 3919) – Final Report – March 2024 – Iman Soltani, AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/t3919-targeted-messages-final-report-3.pdf

From the abstract: This report details the development and evaluation of an innovative component in a traffic management system aimed at enhancing safety in work zones through targeted warning messages. The primary objective of the system is to improve the rates of driver compliance with work zone guidelines presented on signages and message boards, which our studies have shown to be a critical factor in ensuring worker safety near temporary lane closures. By personalizing messages for individual vehicles based on specific characteristics, such as make, model, and color, the system may increase the likelihood of driver adherence to safe speed and driving behavior. Our research evaluated two systems: a custom artificial intelligence-based Vehicle Make and Model Recognition (VMMR) system and a commercial off-the-shelf solution. Both systems underwent extensive field testing, demonstrating promising results in vehicle detection and VMMR accuracy. Based on our findings, we recommend that Caltrans adopt the commercial off-the-shelf camera system for its comprehensive capabilities and support. Additionally, we suggest strategic placement of the camera and message board further from the lane closure, allowing drivers ample time to respond to the targeted warnings, thereby enhancing overall safety and traffic flow."

Managing Low Volume Access Points in Work Zones (Task 3149) – Final Report – July 2020 – Sean Donahue, Bahram Ravani, AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca20-3149-finalreport-v2-a11y.pdf

From the abstract: This research study evaluated methods of traffic control for mitigating wrong way movements from low volume access points in work zones that use reversible control. A literature review was conducted to identify traffic control systems that could address this problem. The most relevant devices found were a type of traffic control system known as a Driveway Assistance Device (DAD). A commercial DAD was selected for testing that was made by Superior Traffic Services (STS) of Missoula, Montana. A test plan along with a test protocol was developed and testing was conducted. Testing was conducted in two groups using a total of 11 volunteer test drivers. Of the 11 test drives, two drivers entered the intersection when a red signal was displayed by the DAD. Some driver anxiety was observed about unknown wait times, so it was recommended that the onboard Changeable Message Sign (CMS) be used to display wait times. Testing with the onboard CMS was not conducted due to impacts from the COVID-19 pandemic and other reasons. In addition to testing of existing equipment, new concepts were synthesized. These new concepts included using machine vision to ensure that all vehicles that entered the work zone exited before the traffic direction is reversed and adding micro radio transmitters to a Traffic Control System (TCS) in order to provide directions to motorists. A proposal was also generated for modifications that can be made to existing DADs that included adding a gate arm and adding an intrusion detection system."

Evaluation of Remote-Control Mowers for Roadside Management (Task 2730) – Final Report – October 2019 – Wilderich White, Ty A. Lasky, AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca20-2730-finalreport-a11y.pdf

From the abstract: This report presents results for research evaluating remote control mowers for roadside management. Caltrans is interested in this technology as a potentially new approach for mowing steep slopes where tractor-based mowing is too hazardous or otherwise unfeasible. Commercially available remote-control mowers show great promise for safely and efficiently managing vegetation on steep slopes and in constrained areas. This research evaluated the applicability of remote-control mower systems for Caltrans operations. This evaluation includes two seasons of field testing with Caltrans operators, including operators' feedback on their experiences with the systems."

Evaluation of Work Zone Intrusion Alarms Ghazan Khan, Shukurat Sanni, Steffen Berr, Kevan Shafizadeh, August 14, 2019, Report Number CA 19-3038

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca19-3038-finalreport-a11y.pdf

From the abstract: The main goal of this research was to evaluate the effectiveness of work zone intrusion alarm (WZIA) systems and assess their readiness to be deployed in California work zones. Four WZIA systems were selected for evaluation; one of which was subsequently dropped because of unavailability of the device. A detailed evaluation framework was developed to assess the performance of each system and understand their capabilities, issues, and limitations. Pilot testing was conducted resulting in some known issues from the literature, and other new issues and unexpected results; followed by supplemental testing to better assess the systems' capabilities and strengthen the conclusions derived. The final results showed that the Worker Alert System (WAS) performed well with certain limitations and differences observed from the manufacturer's specifications. The SonoBlaster system encountered several issues and limitations, most of which could not be resolved or corrected. The Intellicone system's intermittent issues observed during the pilot testing were resolved after extensive tests and consultation with the manufacturer and all subsequent trials were successful. Supplemental
plans to the Caltrans standard work zone traffic control plans were developed which describe the deployment location, range distances, and setup of the Intellicone and WAS. Implementation of the Intellicone and WAS in California work zones could provide additional safety benefits, supplementing existing safety practices for the benefit of work zone workers and reducing work zone fatalities."

Vision-Based Sensor System for Site Monitoring: Wrong-Way Driving, Phase 1 (Task 2970) – Final Report – June 2020 – Ty A. Lasky, Kin Yen, Stephen Donecker, Wil White, Duane Bennett, Travis Swanston, and Bahram Ravani - AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca20-2970-finalreport-a11y.pdf

Connected Vehicle Application Development (Task 3287) – Final Report – September 2023 – Kun Zhou, California Partners for Advanced Transportation Technology (PATH) University of California, Berkeley

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/task-3287-final-report-a11y.pdf

Connected Autonomous Vehicles: Safety During Merging and Lane Change and Impact on Traffic Flow (Task 3405) – Final Report – September 2020 - Petros Ioannou & Fernando V. Monteiro, University of Southern California

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca20-3405-finalreport-a11y.pdf

Evaluation of Autonomous Vehicles and Smart Technologies for Their Impact on Traffic Safety and Traffic Congestion (Task 3406) – Final Report – June 2020 - James Miles & Thomas Strybel, California State University, Long Beach

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca20-3406-finalreport-a11y.pdf

Roadside Safety Performance Measures for Specific Countermeasures to Protect Workers (Task 4163) – Final Report – December 2023 – Anh Duong, Iman Soltani, and Ty Lasky, AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ucd-arr-23-12-31-02-unsecure-a11y.pdf

DRISI Project Final Reports (Before 2019)

Field Experiment of Variable Speed Advisory (VSA) (Task 2447) – Final Report – September 2018 – Xiao-Yun Lu, John Spring - California Partners for Advanced Transportation Technology (PATH) University of California, Berkeley

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca18-2447-finalreport-a11y.pdf

Support for Challenge Area "Work Zone" (Task 3041) – Final Report – June 2017 – Patricia Fyhrie, Bahram Ravani, AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0017134-ca18-3041-finalreport.pdf

From the abstract: This research study focused on the support of the "Work Zone Challenge Area" (WZCA) component of California's Strategic Highway Safety Plan (SHSP). The WZCA is charged with improving the safety of work zones and reducing the number of fatalities and serious injuries due to work zone related traffic collisions. The WZCA team has identified strategies to address this charge with subsequent "Action Items" to help implement these strategies. This research study led two action items. These action items are supporting the "Apply advanced technology to improve work zone safety" and the "Improve work zone data collection and analysis" as part of WZCA strategies. Focusing on "data driven" solutions to the WZCA challenge, a review of existing technologies, practices and applications was done to help identify any new technology or "in the field application" that may be of interest to the WZCA team. With respect to traffic related data, AHMCT made use of databases associated with Traffic Collision Reports (TCRs) such as Traffic Accidents Surveillance and Analysis System (TASAS) and Statewide Integrated Traffic Records System (SWITRS) to capture more collision content and associated attributes. Specifically, the research found what data is available for work zone traffic collisions, and the current study provides a detailed explanation of where the data is derived and what it contains to evaluate work zone safety. Data analysis from these sources are also provided to support the WZCA team's efforts. The description of data and how it can be used to better understand work zone collisions are aimed at the traffic safety community."

Work Zone Injury Data Collection and Analysis (Task 2257) – Final Report – June 2015 – Bahram Ravani, Patricia Fyhrie, Kristopher Wehage, Arash Gobal, and Hiu Y. Hong - AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0017164-ca16-2257-finalreport-a11y.pdf

From the abstract: Work-zone related injuries and fatalities are a major safety concern in California and nationwide. Developing mitigation measures is vital in improving work zone safety both for roadway workers as well as the traveling public. Developing such measures, however, require detailed data on the characteristics of these accidents and injuries produced in them as well as injury costs models that can be used for cost benefit assessments. Although there exist databases and data sources such as the Statewide Integrated Traffic Records Systems (SWITRS), NHTSA's (National Highway Traffic Safety Administration's) FARS (Fatality Analysis Repotting System) database, and Caltrans TASAS (Traffic Accident Surveillance and Analysis System), none can provide the information that would justify particular mitigation measures, or allow cost benefit analysis. This research was conducted to develop such data, codify and classify it in terms of factors and outcomes and provide analysis tools in terms of injury costs. It involved collecting, codifying and classifying all Traffic Collison Reports for accidents occurring near a work-zone from 12 Caltrans districts for a period of five years (2006-2010). Extracted data from these reports were codified in terms of factors and outcomes and made part of a decision support system designed to allow analysis of the data that can be used for planning and management of work-zone operations to improve worker and motorist safety."

Evaluation of Methods to Reduce Speed in Work Zones (Task 2405) – Final Report – June 2015 – Bahram Ravani, Patricia Fyhrie, Chao Wang, Wil White, Samuel E. Isaiah, AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca15-2405-finalreport-a11y.pdf

From the abstract: This study involved an evaluation of the effectiveness of the California Highway Patrol (CHP) combination Radar Detection/Changeable Message Sign (CMS) (CHP-CMS) trailers to manage traffic speeds in highway work zones. The CHP-CMS trailer is a radar-equipped CMS trailer unit outfitted with revolving or flashing lights similar to those used on CHP vehicles. The main objective of this s study was to test the following hypothesis: does the CHP-CMS trailer unit provide an effective deterrent to speeding, thereby slowing traffic in the work zones? The results of this study validated this hypothesis with the understanding that the validation was based on limited (a total of three) field tests due to the limited scope and time duration of this study as well as availability of actual work zones for testing. Further testing is recommended in the future. The research developed a repeatable test methodology based on the us e of easily deployable s peed sensors distributed throughout the work z one. Additional sensors w ere also used f or validation and collection of other pertinent da ta. Data was also collected on the combined utilization of the CHP-CMS trailer and a CHP vehicle as in MAZEEP (Maintenance Zone Enhanced Enforcement Program) and its effect on traffic speed reduction at work zones. The overall conclusion of this study is that the use of the CHP-CMS system does result in a deterrent to speeding vehicles near work zones and its use can therefore improve work zone safety."

A Cooperative V2V Alert System to Mitigate Vehicular Traffic Shock Waves (Task 2962) – Final Report – April 2017 – Mario Gerla, University of California at Los Angeles

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0017145-ca17-2962-finalreport.pdf.

From the abstract: Vehicle traffic on highway systems are typically not uniformly distributed. In our work, we introduce a protocol that exploits this phenomenon by considering the formations of shock waves and opportunities in adjacent lanes. The objective of this protocol is to reduce the impact of a shock wave by using event driven messages between vehicles that provide drivers with velocity or lane switching recommendations. We show how our protocol uniformly distributes vehicle densities across multiple lanes while maintaining lane fairness, and reduces the number of vehicles entering a shock wave point. Simulation results show we are able to further reduce the overall travel times and increase the average velocity."

Executive Summary for the UC Berkeley, California PATH's Augmented Speed Enforcement Project (Task 2146B) – Final Report – October 2013 - Ching-Yao Chan, Somak Datta Gupta - California Partners for Advanced Transportation Technology (PATH), University of California, Berkeley

https://dot.ca.gov/file-unavailable?filepath=http://dot.ca.gov/-research/researchreports/reports/2013/final_report_task_2146a.pdf

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0017181-final-report-task-2146b.pdf

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0017187-final-report-task-2062b.pdf

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0017186-final-report-task-2062c.pdf

Evaluation of Photo Speed Enforcement (PSE) in California Work Zones (Task 2247) – Final Report – June 2015 – Bahram Ravani, Patricia Fyhrie, Chao Wang, Wil White, Samuel E. Isaiah, AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca13-2247-finalreport-a11y.pdf

Development of New Kinds of Mobile Safety Barriers (Task 0920) – Final Report – February 2009 – George Burkett, Vue Her, Steven A. Velinsky, AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca09-0920-finalreport-a11y.pdf

Work Zone Intrusion Countermeasure Identification, Assessment, and Implementation Guidelines (Task 1102) – Final Report – May 2010 – Gerald L. Ullman, Melisa D. Finley, LuAnn Theiss, Texas Transportation Institute

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0016954-final-report-task-1102.pdf

Work Zone Safety Improvements through Enhanced Warning Signal Devices (Task 0819) – Final Report – January 2008 – Kent Christianson, Daniel Greenhouse, Theodore Cohn, Roy Young Kim, Christina Chow, California Partners for Advanced Transportation Technology (PATH), University of California, Berkeley

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0016969-task-0819-final-report.pdf

DRISI Preliminary Investigations Reports

DRISI Preliminary Investigations Reports with material related to ACT and RVI are listed below.

DRISI Preliminary Investigations Reports (2019 – 2024)

Work Zone Safety: Synthesis of Literature and Industry Survey (PI-296) - Preliminary Investigations Report requested by Rachel Carpenter, Division of Safety Programs July 27, 2021

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/pi-0296-a11y.pdf

Teleoperated, Connected, and Automated Vehicles and Equipment for Maintenance Operations Preliminary Investigations Report requested by Ed Hardiman, Caltrans, Division of Equipment March 1, 2021

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/pi-0297-a11y.pdf

Life Cycle Planning for Intelligent Transportation System Assets: Survey of Practice Preliminary Investigations Report requested by Dawn Foster, Caltrans, Office of Asset Management June 11, 2021

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/pi-0261-a11y.pdf

Automated LiDAR Extraction Software - Preliminary Investigations Report requested by Chris Thornton, Division of Right of Way and Land Surveys October 18, 2021

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/pi-0324-a11y.pdf

DRISI Preliminary Investigations Reports (Before 2019)

Replacing Intelligent Transportation System Field Elements: A Survey of State Practice - Preliminary Investigations Report requested by Ferdinand Milanes, Division of Maintenance January 8, 2016

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/replacing-its-field-elements-pi-a11y.pdf

Variances in Advance Warning Signs – Preliminary Investigations Report requested by Theresa Drum, Division of Maintenance April 6, 2015

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/advance-warning-signs-pi-04-06-15-no-appendices-b-to-f1-a11y.pdf

In-Vehicle Safety Warnings – Preliminary Investigations Report requested by Anthony Lopez, District 6, Office of Traffic Electrical, October 13, 2017

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/in-vehicle-safety-warnings-pi-a11y.pdf

Work Zone Intrusion Alarms for Highway Workers – Preliminary Investigations Report requested by Theresa Drum, Division of Maintenance April 5, 2016

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/work-zone-warning-pi-a11y.pdf

Highway Worker Safety: Technologies – Preliminary Investigations Report requested by Larry Orcutt, Chief, Caltrans Division of Research and Innovation, July 11, 2011

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/hwy-safety-technologies-pi-a11y.pdf

Highway Worker Safety: Automated Speed Enforcement – Preliminary Investigations Report requested by Rebecca Boyer, Caltrans Division of Research and Innovation, August 3, 2011

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/automated-speed-enforcement-pi-8-3-11-a11y.pdf

Highway Worker Safety: Policies, Practices and Legal Issues – Preliminary Investigations Report requested by Larry Orcutt, Chief, Caltrans Division of Research and Innovation, July 11, 2011

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/hwy-safety-policies-and-legal-issues-pi-a11y.pdf

Highway Worker Safety: Education and Outreach – Preliminary Investigations Report requested by Larry Orcutt, Chief, Caltrans Division of Research and Innovation, July 11, 2011

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/hwy-safety-education-and-outreach-pi-a11y.pdf

Development of New Kinds of Mobile Safety Barriers (Task 0920) – Final Report – February 2009 – George Burkett, Vue Her, Steven A. Velinsky, AHMCT Research Center, University of California, Davis

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca09-0920-finalreport-a11y.pdf

Other Nationally Affiliated Research Publications

Publications with material related to ACT and RVI by other nationally affiliated organizations or institutions are listed below.

FHWA/ARTBA/Texas A&M – Synthesis of Research related to the Use and Implementation of Advanced Technology in Work Zones to Improve Work Zone Management, 2022

https://workzonesafety-media.s3.amazonaws.com/workzonesafety/files/documents/training/fhwa_wz_grant/artba_synthesis_advanced_technology_wz_management-2022.pdf

FHWA/IN/JTRP-2024/22 - Purdue University - Impacts of Autonomous Truck-Mounted Attenuator (ATMA) on INDOT Work Zone Safety, Mobility and Worker Productivity

Impacts of Autonomous Truck-Mounted Attenuator (ATMA) on INDOT Work Zone Safety, Mobility, and Worker Productivity

FHWACA10-1102 - Work Zone Intrusion Countermeasure Identification, Assess, And Implementation Guidelines

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0016954-final-report-task-1102.pdf

FHWA-JPO-10-059 - California Deployment of Portable Concrete Monitoring Devices

https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/f0017227-saic-final-california-6-14-2010.pdf

FHWA/TX-24/0-7118-R1 - IMPROVING SMART WORK ZONE DEPLOYMENTS IN TEXAS

https://static.tti.tamu.edu/tti.tamu.edu/documents/0-7118-R1.pdf

MTI Project Number 2453 -Inspection Technologies for Construction and Maintenance of Highway Infrastructure – Review and Analysis, 2025, Manideep Tummalapudi, Prem Raj Timilsena, Mineta Transportation Institute

https://transweb.sjsu.edu/research/2357-Infrastructure-Inspection-Highway-Construction-ARVR

MTI Project Number 2357 - Survey of Building Information Modeling for Infrastructure (BIM4I), 2025, Maria Calahorra-Jimenez, Nigel Blampied, Elhami Nasr, Tariq Shehab, Mineta Transportation Institute

https://transweb.sjsu.edu/mceest/research/utc/Survey-Building-Information-Modeling-Infrastructure-BIM4I