In-Vehicle Safety Warnings

Requested by
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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

Caltrans maintains a wide range of intelligent transportation system (ITS) data in its Commercial Wholesale Web Portal 2 (CWWP2; see http://www1.dot.ca.gov/cwwp2/). CWWP2 contains ITS field data that has been reviewed and given precise location information as well as real-time status information. This ITS field data is associated with changeable message signs (CMS), closed circuit television cameras, roadside weather information systems, lane closures and more.

The ITS field data is typically used to create alerts for motorists on fixed or portable CMS. Caltrans is interested in using this data to create in-vehicle safety warnings for drivers (for example, warnings about slowed traffic ahead due to poor visibility) that could be provided on an integrated system (a car dashboard display) or a mobile device (a smartphone). These warning applications should be geospatially specific, providing warnings to drivers in appropriate locations, and the applications should be appropriate for use in rural areas where cell coverage may be limited.

To gather information for this Preliminary Investigation, CTC & Associates examined efforts by Caltrans districts, state departments of transportation (DOTs) and national agencies to use ITS data to deliver in-vehicle safety warnings to drivers.

Summary of Findings

Current Caltrans Practices

We queried the 12 Caltrans districts to determine if efforts to use ITS data to generate in-vehicle safety warnings were planned or underway within the agency. None of the three responding districts are using CWWP2 data to generate these warnings, although two districts reported on other ITS-related activities.

- In District 6, plans are underway to develop a virtual CMS (VCMS) using a Satellite Operation Center application. Rather than using a physical CMS to generate an advisory or warning, a VCMS will generate the message for display on QuickMap, Caltrans' online tool that provides real-time information about freeway congestion and commuting trouble spots.
- District 7 expects to participate in the larger Caltrans effort to partner with Waze to deliver traffic-related data. (Waze is a community-based traffic and navigation mobile app used by motorists to share real-time traffic and road information.) The district is also planning to pilot an unspecified third-party application as part of its participation in the Caltrans Connected Corridors Program.

National Research Efforts

Federal Highway Administration

Federal Highway Administration (FHWA) staff with a range of ITS-related experience highlighted the following projects and activities that might inform Caltrans' development of an in-vehicle safety warning application:

Vehicle-to-infrastructure safety applications. FHWA's ITS and Connected Vehicle Program has conducted wide-ranging research that examined vehicle-to-infrastructure safety applications, including the Spot Weather Information Warning (SWIW), which generates two types of warnings:

- Suggested or required diversion to an alternate route to avoid the adverse weather zone and closure.
- An alert of a vehicle's speed that may be too high to safely traverse the zone.

FHWA is not pursuing the SWIW application for further development beyond the performance requirements documents. These documents "provide requirements for both infrastructure and vehicle application components to ensure the messages are consistent and coordinated, to best capture the attention of the driver and to avoid conflicting or confusing driver messaging."

Connected Vehicle Pilot Deployment Program. The ITS Joint Program Office is overseeing a pilot program that uses three sites to "deploy, test and operationalize cutting-edge mobile and roadside technologies and enable multiple CV [connected vehicle] applications." Test sites include New York City; Tampa, Florida; and Wyoming. See pages 8 and 28 of this Preliminary Investigation for more information about the Wyoming DOT pilot, which uses ITS data for traveler alerts.

Weather-related data and warnings. Similar to the road weather information system data already gathered by state DOTs, FHWA's Weather Data Environment (WxDE) adds a step by conducting quality checks and running data through a vehicle data translator known as Pikalert. Pikalert, an open-source software program, is used in WxDE and Wyoming DOT's Connected Vehicle Pilot Deployment Program.

Work Zone Data Initiative. This project, which kicked off in fiscal year 2017, will produce a state-of-the-practice synthesis on agency collection and use of work zone activity data (WZAD). Researchers will identify use cases for WZAD, develop minimum data requirements and develop agency guidance for WZAD recordkeeping. Candidate agencies will be identified for participation in a pilot project, scheduled for fiscal year 2018-2019, that implements a Work Zone Data Exchange.

Former Research and Innovative Technology Administration

Research projects sponsored by the Research and Innovative Technology Administration (now part of the Office of the Secretary of Transportation) addressed in-vehicle warnings in three topic areas:

- Development of a mobile user interface.
- Use of smartphones to provide audible warnings to drivers.
- Driver behavior related to the use of in-vehicle warning devices and smartphone applications.

Other National Efforts

We conclude an examination of national efforts with information about the Connected Vehicle Pooled Fund Study, a group of state and local transportation agencies and FHWA that has come together to "conduct the work necessary for infrastructure providers to play a leading role in advancing the Connected Vehicle systems." Among the pooled fund's current activities is a project to develop a Basic Infrastructure Message (BIM) and standards for the use of the message. A standard BIM will assist original equipment manufacturers, third-party application providers and public transportation agencies in managing the information broadcast from roadside equipment. We also provide a sampling of the communication standards completed and in process by SAE International in connection with dedicated short range communications (DSRC) messages.

State Research Efforts

Below are summaries of interviews and a sampling of published research that describe recent research efforts in five states—Iowa, Michigan, Minnesota, Texas and Wyoming.

Iowa (see page 20)

Iowa DOT's Automated Vehicle Technologies Project began in 2016 with the development of a custom vehicle to test and ingest data for multiple "use cases" (types of information that can be ingested to appear on an in-dash display), including:

- Crash.
- Weather.
- Obstacle.
- Work zones.
- Wide moving jam.
- Event congestion.

The project team is focusing on three use cases in its initial testing: work zones, weather and wide moving jam. A small proof of concept was conducted this summer; a larger-scale pilot will be conducted this fall. The conceptualized system has two key components:

- High-definition (HD)/3-D cloud-based digital mapping of paved roads with centimeter-level accuracy that is ingested by the vehicle.
- Predictive travel modeling and validation that is also ingested by the vehicle.

The new technology is expected to work in all weather conditions, predict anticipated traffic and roadway conditions, communicate seamlessly with other automated vehicles and use HD mapping for precise vehicle location.

Project team members noted the significance of data quality and formatting, and indicated that this spring's proof-of-concept testing highlighted the need for more accurate data. While the data are appropriate for use in connection with the agency's 511 system and for traffic management, the same data sets are not accurate enough for use in connection with an automated vehicle.

Michigan (see page 23)

Michigan DOT has not developed or deployed an in-vehicle messaging and warning system of the type envisioned by Caltrans, though the agency does provide in-vehicle parking availability messaging to limited commercial vehicles as part of its Truck Smart Parking Services initiative.

The agency has also demonstrated motorist advisories and warnings through an FHWA grant. This 2015 research used a cellphone application tied to the agency's Mi Drive traveler information web site to generate weather-related warnings. Our interviewee noted that beyond those efforts, the agency "ha[s]n't fully explored the heads-up displays and/or in-vehicle warnings to drivers."

Minnesota (see page 24)

Minnesota DOT (MnDOT) has conducted connected vehicle research that examined elements of the application Caltrans envisions, including an examination of the human factors associated with in-vehicle warning systems. Our interviewee noted that MnDOT would be interested in the type of warning system Caltrans envisions, and describes the agency's current connected vehicle research as a "fluid environment." The MnDOT research we highlight assessed the feasibility of using consumer devices for implementing connected vehicle applications and the use of DSRC to deliver driver warnings and alerts in rural areas with limited cellular coverage.

Texas (see page 27)

Southwest Research Institute (SwRI) has been actively involved in ITS-related research since 1992. An SwRI engineer noted that many of SwRI's projects have focused on back-end systems that are outside the realm of interest for this project (parking schedules for airports, transit, commercial vehicles, truck packing and route restrictions, and commercial vehicle infrastructure integration).

A few highlights from our discussion:

- DSRC can be an effective communication mechanism when two vehicles meet each other in a rural setting. The technology offers high availability but low latency, and can be effective when used for localized messages such as queue warnings.
- For messages where there is more time to deliver the message (notifying the driver of a construction site far ahead), other methods such as cellular communication can be used.

Wyoming (see page 28)

The Wyoming Connected Vehicle Pilot Deployment Program is one of three FHWA pilot projects that will test and deploy advanced DSRC technology to improve safety and mobility. In Wyoming, this technology will be used to improve monitoring and reporting of road conditions to vehicles on Interstate 80.

Wyoming DOT will use vehicle-to-vehicle, vehicle-to-infrastructure and infrastructure-to-vehicle connectivity to deliver real-time information associated with incidents, construction, variable speed limits, road conditions and more via a Traffic Management Data Dictionary (TMDD) v3.03c data feed. (A sample of the TMDD data feed appears in Attachment A.) The TMDD data feed is provided through a representational state transfer (REST) endpoint that presents the file in JavaScript object notation (JSON) format. The agency has identified at least one unspecified partner willing to make this information available via the partner's in-vehicle navigation system. Similar information will be available via the connected vehicle operational data environment, and Sirius XM may pick up Wyoming DOT's data via this feed.

Warnings developed in the pilot include the following:

- *Spot weather impact warning*. Enables localized road condition information, such as fog or icy roads, to be broadcast from a roadside unit and received by a connected vehicle.
- *Situational awareness*. Provides relevant road condition information including weather alerts, speed restrictions, vehicle restrictions, road conditions, incidents, parking and road closures. The information is broadcast from roadside units and received by the connected vehicle.
- *Work zone warning*. Communicates information to approaching vehicles about conditions at a work zone ahead. Approaching vehicles receive information about work zone activities or restriction information that could present unsafe conditions, such as obstructions in a vehicle's travel lane, lane closures, lane shifts, speed reductions or vehicles entering or exiting the work zone.

Testing will begin on Wyoming DOT fleet vehicles (highway patrol vehicles, snowplows and other partner vehicles) in the fall/winter of 2017 to 2018. The pilot will expand to testing with commercial vehicles in the fall/winter of 2018 to 2019.

Gaps in Findings

While we found completed research and research in progress that involves elements of the in-vehicle safety warning system of interest to Caltrans, none of the research we reviewed appears to incorporate all elements of the envisioned system. For example, Wyoming DOT's pilot project has a greater focus on commercial rather than passenger vehicles, and Iowa DOT's research employs more connected vehicle technology than may be of interest to Caltrans. While none of the research efforts highlighted in this report appear to replicate the system Caltrans envisions in its entirety, the research activities we highlight may inform Caltrans' continued examination of the use of ITS data to deliver in-vehicle safety warnings.

The scope of this Preliminary Investigation did not permit an exhaustive review of all research that may relate to Caltrans' interest in an in-vehicle warning system. There may be other research activities planned or in process that we did not uncover that may be relevant.

Next Steps

Moving forward, Caltrans could consider:

- Reviewing the performance requirements documents developed by FHWA that describe the infrastructure and vehicle application components of a spot weather information warning.
- Examining in more detail the research projects sponsored by the former Research and Innovative Technology Administration that developed a mobile user interface and used smartphones to deliver audible warnings to drivers.
- Contacting Iowa DOT to learn more about the agency's generation and delivery of a weather-related warning, and the data quality issues identified by the Automated Vehicle Technologies Project team.
- Consulting with MnDOT to explore the agency's shared interest in the type of in-vehicle warning system Caltrans envisions.
- Consulting with Wyoming DOT about the development of data feeds and other aspects of the in-vehicle warning system in development.

Detailed Findings

Current Caltrans Practices

Background

Caltrans' Commercial Wholesale Web Portal, Version 2 (CWWP2), contains intelligent transportation system (ITS) field data that has been reviewed and given precise location information as well as real-time status information. CWWP2 contains ITS data for:

- Changeable message signs (CMS).
- Closed circuit television cameras.
- Roadside weather information systems (RWIS).
- Lane closures.
- Chain control signs.

The CWWP2 data sets are provided in four formats that third-party application developers can use to integrate Caltrans' traveler information data into their applications. More information about CWWP2 is available at www.dot.ca.gov/cwwp2/.

Caltrans sees potential benefit in developing tools to use the ITS data housed in CWWP2 to create in-vehicle safety warnings for drivers, such as alerts about slowed traffic ahead due to poor visibility. These alerts could be provided via smartphones or an in-dash display.

Before examining national and state efforts to use ITS data to generate these types of in-vehicle warnings, we queried Caltrans districts to determine if such efforts might already be planned or underway within the agency.

District Feedback

Three of the 12 Caltrans districts responded to a request for information about district activities related to the use of CWWP2 data and development of in-vehicle safety warnings. None of the responding districts are using CWWP2 data to generate these warnings, although two districts reported on other ITS-related activities. Below is a summary of district responses.

District 6

District 6 provides ITS-related data to CWWP2 and QuickMap, Caltrans' online tool providing real-time information about freeway congestion and commuting trouble spots. Launched in 2012, this interactive travel map accesses freeway cameras and CMS on highways statewide to assist users in monitoring traffic congestion, incidents and lane closures.

Project in Process

Plans are underway for to develop a virtual CMS (VCMS) using a Satellite Operation Center application. Rather than using a physical CMS to generate an advisory or warning, a VCMS will generate the message for display on QuickMap. The VCMS will be placed strategically within the application at locations where a physical CMS will eventually be installed. The new VCMS

will be part of a closed system and will not generate the type of in-vehicle warnings envisioned by the project panel.

Other Uses of ITS Data

The district generates and monitors ITS data associated with two warning systems. Both systems, described below, are directional and location-specific but do not generate in-vehicle alerts.

- Fog Detection and Warning System (FDWS) generates weather alerts (the presence of fog or reduced visibility), as well as alerts associated with traffic and variable speed conditions, for display on a nonstandard CMS. Caltrans does not own the FDWS application, which was developed by a consultant as a turnkey application. The project contract did not provide for FDWS data to be distributed to CWWP2.
- Truck Escape Ramps (TER) provides alerts to motorists via an extinguishable message sign when an escape ramp is occupied. The same message is sent to a Traffic Management Center operator. TER was developed internally by District 6 staff. Data from TER is not currently provided to CWWP2.

After transmitting the data to CWWP2, data associated with FDWS and TER could be delivered via the in-vehicle safety warning now under consideration by the project panel.

Related Resources

QuickMap, Caltrans, 2016.
http://quickmap.dot.ca.gov/
From the web site: The Caltrans QuickMap web page presents several types of real-time traffic information layered on a Google Map. The information includes traffic speed, lane and road closures due to construction and maintenance activities, incident reports, Changeable Message Sign (CMS) content, camera snapshots, and active chain control requirements. Traffic speed is indicated by color-coded lines overlaying the roadway. The location of information content for the remaining layers is identified by markers (icon images) on the map. Clicking on a marker displays the information details in an info window pop-up.

"Fog Detection and Warning System (FDWS)," John Liu, District 6, Caltrans, *Talking Technology and Transportation (T3) Webinars*, ITS Joint Program Office, January 2013.
https://www.pcb.its.dot.gov/t3/s130130/s130130_caltrans.pdf
This webinar presentation provides project background and an overview of FDWS, concluding with a discussion of ongoing issues and what's next for the application.

"Run-Away Truck Escape Ramp: A Trucker's Safety Net," Jose De Alba, District 6, Caltrans, *Western States Rural Transportation Technology Implementers Forum*, July 2009.
http://www.westernstatesforum.org/Documents/2009/CaltransD6_deAlba_TruckEscapeRamp_07-08-09.pdf
This conference presentation describes the TER system.

District 7

District 7 expects to participate in the larger Caltrans effort to partner with Waze, to deliver traffic-related data (Waze is a community-based traffic and navigation mobile app used by motorists to share real-time traffic and road information.) The district is also planning to pilot an

unspecified third-party application as part of its participation in the Caltrans Connected Corridors Program.

Project in Process

A June 2015 concept of operations describes the district's I-210 Pilot Integrated Corridor Management System project (see Related Resources below). The project "aims to develop strategies for the coordinated management of the I-210 freeway, surrounding arterials, and other relevant transportation systems to improve overall mobility within the corridor. At this stage, the focus is on managing travel conditions during incidents and events having a significant impact on travel activities." The project seeks to make operational gains through:

- Enhancements in traffic- and travel-monitoring capabilities.
- Expansion of data communication capabilities across agencies.
- Deployment of corridor operational evaluation tools suitable for real-time operations.
- Cross-jurisdictional cooperation.

Related Resources

Waze, Waze Mobile, 2017.
https://www.waze.com/
From the web site: After typing in their destination address, users just drive with the app open on their phone to passively contribute traffic and other road data, but they can also take a more active role by sharing road reports on accidents, police traps, or any other hazards along the way, helping to give other users in the area a 'heads-up' about what's to come.

In addition to the local communities of drivers using the app, Waze is also home to an active community of online map editors who ensure that the data in their areas is as up-to-date as possible.

Connected Corridors: I-210 Pilot Integrated Corridor Management System; Concept of Operations, Partners for Advanced Transportation Technology, June 2015.
http://connected-corridors.berkeley.edu/sites/default/files/Concept%20of%20Operations%20I-210%20Pilot%20%282015-06-15%29.pdf.
This document provides a system overview, descriptions of various operational scenarios and a summary of impacts.

District 9

District 9 has not used CWWP2 data to deliver in-vehicle driver alerts and is not aware of other organizations seeking to develop a similar capability.

National Research Efforts

Below we highlight research efforts on a national scale that sought to develop in-vehicle safety applications and consider how those applications impact users, and the data and standards applicable to the types of in-vehicle warnings of interest to Caltrans. Contact information and a brief summary of research activities is followed by a sampling of relevant citations associated with the following research organizations and topic areas:

- Federal Highway Administration.
- Former Research and Innovative Technology Administration.
- Connected Vehicle Pooled Fund Study.
- Communication standards.

Federal Highway Administration

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Todd Peterson, Project Manager, Work Zone Data Initiative, 202-366-1918, todd.peterson@dot.gov.

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Steve Sill, Program Manager, Vehicle Safety Technology, ITS Architecture and Standards, 202-366-1603, steve.sill@dot.gov.

Karen Timpone, Program Manager, ITS and Connected Vehicle Program, 202-366-2327, karen.timpone@dot.gov.

We contacted Karen Timpone, program manager, ITS and Connected Vehicle Program, to inquire about the Federal Highway Administration's (FHWA's) activities relevant to the in-vehicle safety warnings of interest to Caltrans. Timpone gathered information from subject matter experts within the agency and responded by email with their feedback, which is summarized in the following topic areas:

- Vehicle-to-infrastructure safety applications.
- Connected Vehicle Pilot Deployment Program.
- Weather-related data and warnings.
- Work Zone Data Initiative.

Vehicle-to-Infrastructure Safety Applications

FHWA's ITS and Connected Vehicle Program has conducted wide-ranging research that examined vehicle-to infrastructure (V2I) safety applications that "could potentially provide safety, mobility and environmental improvements to the national highway transportation system."

The Spot Weather Information Warning (SWIW) was among the V2I safety applications included in this research. The SWIW generates two types of warnings:

- Suggested or required diversion to an alternate route to avoid the adverse weather zone and closure.
- An alert of a vehicle's speed that may be too high to safely traverse the zone.

With the SWIW, "[t]he driver is issued an advisory message, alert or warning if the vehicle processing platform determines that, given current operating conditions, a crash-imminent situation is likely to occur due to the weather impacts, and notifies the driver if reduced speed or an alternate route is recommended." Timpone indicated that FHWA is not pursuing the SWIW application for further development beyond the performance requirements documents. These documents "provide requirements for both infrastructure and vehicle application components to ensure the messages are consistent and coordinated, to best capture the attention of the driver and to avoid conflicting or confusing driver messaging."

See Related Resources below for more information about FHWA's V2I safety applications.

Related Resources

The publications below are organized in two categories:

- Connected vehicle safety applications.
- Connected vehicle standards.

Connected Vehicle Safety Applications

Vehicle-to-Infrastructure (V2I) Safety Applications: System Requirements Document, Office of Safety Research and Development, Federal Highway Administration, March 2013.
https://ntl.bts.gov/lib/48000/48500/48526/E6E64D50.pdf
From the abstract: This document describes the system requirements for two connected vehicle V2I safety applications related to work zone safety and speed management. Specifically, these applications are:

- Spot Weather Information Warning (SWIW).
- Reduced Speed Zone Warning (RSZW).

SWIW is explained and illustrated on page 8 of the PDF:

> The objective of SWIW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes in areas prone to adverse weather impacts by warning the vehicle driver that a crash-imminent situation is possible, particularly in extreme situations where precautions are not taken, such as reducing speed or seeking an alternate route. The infrastructure application will collect available infrastructure and vehicle data, most importantly from Road Weather Information Systems (RWIS) and process available data to recommend an appropriate advisory message, alert, and/or warning. Depending

upon the availability of data for validation (e.g., redundant RWIS data source, traffic speeds, etc.), validation of the recommended message may be required from a back office traffic management center (TMC) before the message is posted on the Driver-Infrastructure Interface (DII). An equipped vehicle approaching an equipped roadway segment will receive a message that includes data regarding the message posted on DII; length of adverse weather impact zone [throughout which the driver-vehicle interface (DVI) message should apply]; weather data collected by RWIS; and, if available, the advisory, enforceable speed, and/or diversion to an alternate route as recommended by the infrastructure application. The driver is issued an advisory message, alert or warning if the vehicle processing platform determines that, given current operating conditions, a crash-imminent situation is likely to occur due to the weather impacts, and notifies the driver if reduced speed or an alternate route is recommended. Figure ES-1 illustrates the proposed SWIW application design.

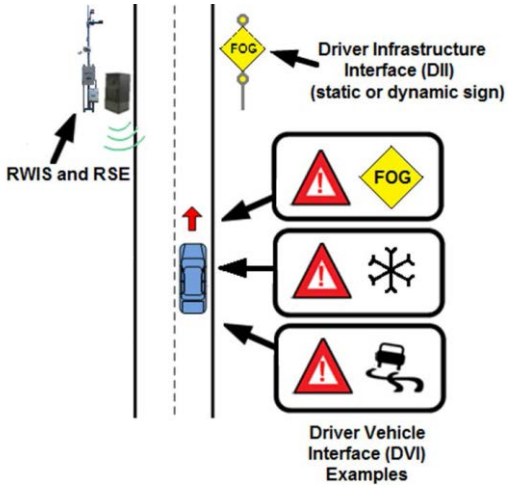

Figure ES-1. SWIW Illustration

The report further details system requirements for V2I safety applications in general and SWIW in detail.

Vehicle-to-Infrastructure (V2I) Safety Applications: Performance Requirements, Vol. 6, Spot Weather Information Warning — Diversion (SWIW-D), Office of Safety Research and Development, Federal Highway Administration, August 2015.
https://ntl.bts.gov/lib/61000/61100/61127/FHWA-JPO-16-253.pdf
From the abstract: This volume describes the Performance Requirements for the infrastructure and vehicle components of the Spot Weather Information Warning — Diversion V2I Safety Application. This application is designed to advise drivers of road closure ahead due to adverse weather conditions and a suggested or required diversion to an alternate route to avoid the adverse weather zone and closure. The safety applications described here integrate roadside and in-vehicle advisories, alerts and warnings to make the driver aware of hazards in time to take action to prevent a potential crash. The performance requirements provide requirements for both infrastructure and vehicle application components to ensure the messages are consistent and coordinated, to best capture the attention of the driver and to avoid conflicting or confusing driver messaging.

Vehicle-to-Infrastructure (V2I) Safety Applications: Performance Requirements, Vol. 5, Spot Weather Information Warning — Reduced Speed (SWIW-RS), Office of Safety Research and Development, Federal Highway Administration, August 2015.
https://ntl.bts.gov/lib/61000/61100/61126/FHWA-JPO-16-252.pdf
From the abstract: This volume describes the Performance Requirements for the infrastructure and vehicle components of the Spot Weather Information Warning — Reduced Speed V2I Safety Application. This application is designed to advise drivers of current adverse weather conditions in an upcoming weather zone and provide an alert if the vehicle's speed may be too high to safely traverse the zone. The safety applications described here integrate roadside and in-vehicle advisories, alerts and warnings to make the driver aware of hazards in time to take action to prevent a potential crash. The performance requirements provide requirements for both infrastructure and vehicle application components to ensure the messages are consistent and coordinated, to best capture the attention of the driver and to avoid conflicting or confusing driver messaging.

Connected Vehicle Standards

Architecture Reference for Cooperative and Intelligent Transportation, ARC-IT, Version 8.0, U.S. Department of Transportation, September 2017.
http://local.iteris.com/arc-it/
From the web site: The Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) provides a common framework for planning, defining, and integrating intelligent transportation systems. It is a mature product that reflects the contributions of a broad cross-section of the ITS community (transportation practitioners, systems engineers, system developers, technology specialists, consultants, etc.).

Development Activities: Connected Vehicle Reference Implementation Architecture (CVRIA), ITS Standards Program, ITS Joint Program Office, U.S. Department of Transportation, undated.
https://www.standards.its.dot.gov/DevelopmentActivities/CVReference
This web site describes connected vehicle-related project activities. As the site indicates, the project was completed in 2014, and project results (architecture viewpoints for 88 connected vehicle safety, mobility, environmental and support applications) are available at http://www.iteris.com/cvria. (See the citation immediately below for information specific to in-vehicle signage.)

TI07: In-Vehicle Signage, Service Packages, Architecture Reference for Cooperative and Intelligent Transportation, ARC-IT, Version 8.0, U.S. Department of Transportation, September 2017.
http://local.iteris.com/arc-it/html/servicepackages/sp115.html#tab-3
From the web site: This service package augments regulatory, warning, and informational signs and signals by providing information directly to drivers through in-vehicle devices. The information provided would include static sign information (e.g., stop, curve warning, guide signs, service signs, and directional signs) and dynamic information (e.g., current signal states including highway intersection and highway-rail intersection status and local conditions warnings identified by local environmental sensors). This service package also includes the capability for maintenance and construction, emergency and transit vehicles to transmit sign information to vehicles in the vicinity so that in vehicle signing can be used without fixed infrastructure in areas such as work zones, around incidents and at bus stops.

Connected Vehicle Pilot Deployment Program

FHWA's ITS Joint Program Office is overseeing a Connected Vehicle Pilot Deployment Program that uses three sites to "deploy, test and operationalize cutting-edge mobile and roadside technologies and enable multiple CV [connected vehicle] applications." Test sites include Wyoming; New York City; and Tampa, Florida.

Timpone noted that the Wyoming Department of Transportation (DOT) pilot "has some analogous scope re[garding] use of ITS data for traveler alerts, including in rural areas." See page 28 of this Preliminary Investigation for more information about the Wyoming DOT Connected Vehicle Pilot Deployment Program.

Related Resources

Connected Vehicle Safety Pilot, ITS Joint Program Office, U.S. Department of Transportation, undated.
https://www.its.dot.gov/research_archives/safety/cv_safetypilot.htm
From the web site: Connected Vehicle Safety Pilot is a research program that demonstrates the readiness of DSRC [dedicated short range communications] based connected vehicle safety applications for nationwide deployment. The vision of the Connected Vehicle Safety Pilot program is to test connected vehicle safety applications in real-world driving scenarios in order to determine their effectiveness at reducing crashes and to ensure that the devices are safe and do not unnecessarily distract motorists or cause unintended consequences.

Connected Vehicle Pilot Deployment Program, ITS Joint Program Office, U.S. Department of Transportation, undated.
https://www.its.dot.gov/pilots/index.htm
This web site provides a jumping off point for information and publications related to the Connected Vehicle Pilot Deployment Program. As the site indicates, the "CV Pilot Deployment Program is a national effort to deploy, test and operationalize cutting-edge mobile and roadside technologies and enable multiple CV applications…. Over the past 12 months, each site has prepared a comprehensive deployment concept to ensure a rapid and efficient connected vehicle capability roll-out. Now the three sites will embark on a new 20-month phase to design, build and test the nation's most complex and extensive deployment of integrated wireless in-vehicle, mobile device and roadside technologies."

Safety Pilot Model Deployment: Lessons Learned and Recommendations for Future Connected Vehicle Activities, Kevin Gay and Valarie Kniss, ITS Joint Program Office, U.S. Department of Transportation, September 2015.
https://ntl.bts.gov/lib/59000/59300/59361/FHWA-JPO-16-363.pdf
From the abstract: This report represents an analysis of activities across all stages of the Safety Pilot Model Deployment including scoping, acquisitions, planning, execution and evaluation. The analysis aimed to identify specific accomplishments, effective activities and strategies, activities or areas needing additional effort, unintended outcomes, and any limitations and obstacles encountered throughout the Model Deployment. It also assessed the roles of organizations and the interactions among these organizations in the project.

Included is an examination of dedicated short range communications (DSRC) device development; device deployment and testing (including in-vehicle installation requirements); and data management.

Weather-Related Data and Warnings

When we asked about other initiatives or research that might relate to the type of in-vehicle warning system that Caltrans envisions, Timpone directed us to FHWA's Weather Data Environment (WxDE). Similar to the RWIS data already gathered by state DOTs, WxDE adds a step by conducting quality checks and running data through the vehicle data translator (VDT, also known as Pikalert) to make it more useful. As Timpone noted, "If you ultimately want to use your RWIS data to feed into some sort of in-vehicle safety warning, you will have to do some processing of the raw data in order to figure out which of the obs[ervations] you want to turn into some sort of alert/warning. Fortunately, we've done all the heavy lifting for you in the develop[ment] of Pikalert, open source software that turns observations into useful information." (See Related Resources below for more information about WxDE and Pikalert.)

Related Resources

Weather Data Environment, Turner-Fairbank Highway Research Center, Federal Highway Administration, undated.
https://wxde.fhwa.dot.gov/
From the web site: The Weather Data Environment (WxDE) is a research project that collects and shares transportation-related weather data with a particular focus on weather data related to connected vehicle applications. The WxDE collects data in real time from both fixed environmental sensor stations and mobile sources. The WxDE computes value-added enhancements to this data, such as by computing quality-check values for observed data and computing inferred weather parameters from vehicle data (e.g., inferring precipitation based on windshield wiper activation). The WxDE archives both collected and computed data. The WxDE supports subscriptions for access to real-time data in near real time generated by individual weather-related connected vehicle projects.

Pikalert-5.0, Open Source Application Development Portal, Federal Highway Administration, December 2016.
https://www.itsforge.net/index.php/community/explore-applications/for-search-results#/41/131
FHWA describes this web site as "[a] channel for distributing and collaborating on transportation-related open source applications. Pikalert is used in FHWA's WxDE and in the Wyoming connected vehicle pilot. See page 28 of this Preliminary Investigation for more information about Wyoming DOT's use of Pikalert.

From the web site's description: The PikalertVDT processes and analyzes connected vehicle observations such as air and road temperature, wiper status, braking and traction control information. It then uses this information in conjunction with standard weather observations to actively assess current road weather conditions. This system is capable of incorporating dense connected vehicle data, where and when available, in order to create a high-resolution picture of road weather conditions.

Work Zone Data Initiative

The Work Zone Data Initiative, which kicked off in fiscal year 2017, will produce a state-of-the-practice synthesis on agency collection and use of work zone activity data (WZAD). Researchers will identify use cases for WZAD, develop minimum data requirements and develop agency guidance for WZAD recordkeeping. Candidate agencies will be identified for participation in a pilot project, scheduled for fiscal year 2018-2019, that implements a Work Zone Data Exchange.

Among the pilot project's deliverables will be integration of a WZAD layer in the Research Data Exchange (https://www.its-rde.net/), which is described as "a core element of the USDOT's Connected Data Systems Program. The Research Data Exchange is intended to support research, analysis, application development and testing."

Related Resource

"FHWA Every Day Counts: Smarter Work Zones," *ATSSA Chapter Meeting*, October 2016.
https://s3.amazonaws.com/media.atssa.com/Member+Services/Chapters/CH/CHVAFHWA+Every+Day+Counts+-+Smarter+WZs.pdf
See slide 17 for a brief description of the Work Zone Data Initiative.

Former Research and Innovative Technology Administration

The research projects cited below were conducted by the Connected Vehicle/Infrastructure University Transportation Center (UTC) at Virginia Tech and were sponsored by the Research and Innovative Technology Administration. (The Research and Innovative Technology Administration was moved to the Office of the Secretary of Transportation by Congress in 2014.) The following provides a sampling of the UTC's connected vehicle research that addresses in-vehicle warnings in three topic areas:

- Development of a mobile user interface.
- Use of smartphones to provide audible warnings to drivers.
- Driver behavior related to the use of in-vehicle warning devices and smartphone applications.

Mobile User Interface Development for the Virginia Connected Corridors, Michael Mollenhauer, Alexandria M. Noble and Zachary R. Doerzaph, Research and Innovative Technology Administration, U.S. Department of Transportation, October 2016.
http://cvi-utc.org/wp-content/uploads/2016/10/Mollenhauer_Mobile-User-Interface-Development-for-the-Virginia-Connected-Corridors_Final.pdf
From the abstract: The purpose of this research and development activity was to build a mobile application with a low-distraction user interface appropriate for use in a connected vehicle (CV) environment. To realize their full potential, future CV applications will involve communicating information to and from drivers during vehicle operation. Mobile devices such as smart phones and tablets may be a reasonable hardware platform to provide this communication. However, there are concerns that a potential increase in driver interaction with CV applications may lead to driver distraction and possible negative impacts on driving safety. The prototype mobile device user interface that was designed and created during this project can be used to test new CV applications, validate their impact on driver safety, and inform future mobile device user interface standards for driving applications.

A Connected Vehicle–Enabled Virtual Dynamic Message Sign System Demonstration and Evaluation on the Virginia Connected Vehicle Test Bed, Hyungjun Park, Simona Babiceanu, Robert Kluger, Brian Smith and David Recht, Research and Innovative Technology Administration, U.S. Department of Transportation, March 2016.
http://cvi-utc.org/wp-content/uploads/2015/11/Park_VDMS-Demonstration-and-Evaluation_Final.pdf
From the abstract: Dynamic message signs (DMSs) are widely used to deliver traveler information. While these have proven to be effective, key limitations exist: (1) the locations of DMSs are fixed, (2) reading a DMS message is distracting to drivers, and (3) installation and maintenance of DMSs is expensive. To address these limitations, a smartphone-based virtual DMS (VDMS) application was developed in the first round of Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) projects. This application used smartphones to provide audible "reading" of DMS messages to drivers.

This project built upon previous work to develop a more advanced, second generation of the VDMS system, that is fully integrated in the Dedicated Short Range Communications (DSRC) environment of the Virginia Connected Vehicle Test Bed. The highlights of the enhanced VDMS system include (1) use of four of 40+ DSRC-based roadside equipment units (RSEs) on the Virginia Connected Vehicle Test Bed, and (2) software (VDMS Manager) that has the capability to virtually "build" new DMSs and to create modified and new messages for those DMSs.

Human Factors Evaluation of an In-Vehicle Active Traffic and Demand Management (ATDM) System, Kayla Sykes, Research and Innovative Technology Administration, U.S. Department of Transportation, February 2016.
http://cvi-utc.org/wp-content/uploads/2016/07/Sykes_Human-Factors-Evaluation-of-an-In-Vehicle-ATDM-System_Final.pdf
From the abstract: This research study focused on the development and subsequent evaluation of an in-vehicle Active Traffic and Demand Management (ATDM) system deployed on Interstate 66 in Northern Virginia. The ATDM elements inside the vehicle allowed drivers to remain consistently aware of traffic conditions and roadway requirements even if external signage was inaccessible. Forty participants were accompanied by a member of the research team and experienced the following in-vehicle device (IVD) features: 1) dynamic speed limits, 2) dynamic lane use/shoulder control, 3) High Occupancy Vehicle (HOV) restrictions, and 4) variable message signs (VMS). This ATDM system was equipped with auditory and visual alerts to notify the driver when relevant information was updated. The research questions addressed distraction, desirability and driver behavior associated with the system. Participant data was collected from the instrumented vehicle, various surveys and researcher observation. Several key findings were uncovered related to each research category: 1) the IVD would not be classified as a distraction according to the National Highway Traffic Safety Association (NHTSA) distraction guidelines, 2) 73% of participants would want the in-vehicle technology in their next vehicle, and 3) the speed limit alert motivated participants to alter their speed (based on both survey results and actual participant speed data).

Prototyping and Evaluating a Smartphone Dynamic Message Sign (DMS) Application, Brian L. Smith, Jiaqi Ma and Hyungjun Park, Research and Innovative Technology Administration, U.S. Department of Transportation, December 2015.
http://cvi-utc.org/wp-content/uploads/2015/12/Smith_Prototyping-and-Evaluating-a-Smartphone-Dynamic-Message-Sign-Application_Final.pdf
From the abstract: First, this research proposed the concept of a Virtual Dynamic Message Sign (VDMS) system utilizing a smartphone-based application to demonstrate and summarize user experience for future deployment. The user survey revealed a positive attitude among

participants toward a VDMS system in terms of both usefulness and satisfaction; the average ratings were −0.90 and −0.81 respectively on a −2 to 2 (Totally agree to Totally disagree) five-point Likert scale. The survey also indicated that most drivers (81.0%) perceived VDMS as a safer way to receive information. Many drivers (66.7%) also felt more comfortable receiving an audible message from a VDMS system rather than a text message on a DMS. The results indicate great user acceptability and the potential for such systems to be deployed by public agencies in the future.

This research also aimed to address the question of whether a VDMS conveys information at least as effectively as existing DMSs. A mixed, repeated-measure experiment was designed using a driver simulator to examine (1) the impacts of driver age, (2) information transmission mode, (3) amount of information, and (4) driving complexity on message comprehension, distraction, and perceived difficulty.

Forty-two people were recruited and each of them participated in a test under different combinations. Participant performance was measured in terms of message comprehension, distraction and self-reported message difficulty level. Results revealed that VDMS generally performs better than DMS across different amounts of information, under different driving conditions, and regardless of driver age. VDMS proved significantly better than DMS in message comprehension under relatively complex conditions. It reduced reaction time to unexpected stimuli (as measured with a reduced time-to-brake of 0.39 seconds), and made the same messages easier to process and retain for drivers than DMS.

Connected Vehicle Pooled Fund Study

The Connected Vehicle Pooled Fund Study was “created by a group of state and local transportation agencies and FHWA in order to provide a means to conduct the work necessary for infrastructure providers to play a leading role in advancing the Connected Vehicle systems.” The pooled fund is conducting research that may be helpful to Caltrans as it continues its examination of in-vehicle safety warnings.

Connected Vehicle Pooled Fund Study: Program to Support the Development and Deployment of Infrastructure Based Connected Vehicle Applications, Pooled Fund Study, Lead Agency: Virginia DOT; Technical Leadership Provider: University of Virginia Center for Transportation Studies, August 2017.
http://www.cts.virginia.edu/cvpfs/
This web site provides links to the pooled fund’s research programs and completed research reports. A current project, Basic Infrastructure Message Development and Standards Support, is examined in more detail on page 20 of this report.

Partnership and Operating Policies, Connected Vehicle Pooled Fund Study: Program to Support the Development and Deployment of Infrastructure Based Connected Vehicle Applications, August 2017.
http://www.cts.virginia.edu/wp-content/uploads/2014/04/Connected-Vehicle-PFS-Charter-v3.5_FINAL-August-2017.pdf
As this policy document indicates, the pooled fund study “focuses on projects that are consistent with, and supportive of, AASHTO’s Connected Vehicle Field Infrastructure Footprint Analysis (https://ntl.bts.gov/lib/52000/52600/52602/FHWA-JPO-14-125_v2.pdf) and USDOT’s Connected Vehicle Strategic Plan (https://www.its.dot.gov/strategicplan/).”

Communication Standards

Several experts interviewed for this project noted the importance of data standards. The citations below provide a sampling of the standards completed and in process by SAE International in connection with DSRC messages. A project in progress by the Connected Vehicle Pooled Fund Study will develop a Basic Infrastructure Message (BIM) and "establish a means to collaborate with the relevant standards development organizations." A standard BIM is also expected to assist original equipment manufacturers, third-party application providers and public transportation agencies in managing the information broadcast from roadside equipment.

Dedicated Short Range Communications (DSRC) Message Set Dictionary, Standard J2735_201603, SAE International, Revised March 30, 2016.
http://standards.sae.org/j2735_201603/
From the web site: This SAE Standard specifies a message set, and its data frames and data elements, specifically for use by applications intended to utilize the 5.9 GHz Dedicated Short Range Communications for Wireless Access in Vehicular Environments (DSRC/WAVE, referenced in this document simply as "DSRC") communications systems. Although the scope of this Standard is focused on DSRC, this message set, and its data frames and data elements, have been designed, to the extent possible, to be of potential use for applications that may be deployed in conjunction with other wireless communications technologies as well. This Standard therefore specifies the definitive message structure and provides sufficient background information to allow readers to properly interpret the message definitions from the point of view of an application developer implementing the messages according to the DSRC Standards.

DSRC Messages for Traveler Information and Basic Information Delivery, Standard J2945/4, Work in Progress, SAE International, undated.
http://standards.sae.org/wip/j2945/4/
From the web site: This standard will serve to re-work and extend the existing SAE J2735 message elements in order to include additional travel and roadway information from the infrastructure to enhance safety awareness and promote the exchange and transfer of such messages types between vehicles and the infrastructure (V2I). Fundamentally this document will outline the needs and detail the system requirements to support a variety of use cases linking to the J2735 effort as other J2945/x documents do. The initial scope will be to revise the structure of the existing "TIM" [traveler information message] message to reflect the lessons learned from the various deployment activities such as the BIM developed by an automotive OEM [original equipment manufacturer] consortium. The objective is to improve the general functionality of the message set in key areas such as message linking, content segmentation, message forwarding within a security framework, and new application areas beyond what is enabled by the TIM. This is anticipated to be a full standard, which will be frequently reissued as further new ATIS [advanced traveler information system]/TIM content is added to the framework to be developed. It is also anticipated that the J2735 document will be revised as content is added in support of this work.

DSRC (Dedicated Short Range Communication) Tech Cmte - Author, SAE International, 2017.
http://profiles.sae.org/tevdsrc/
This web page provides a listing of the standards that have been authored or are in progress under the oversight of the DSRC Technical Committee. Also included are historical references for standards.

Basic Infrastructure Message Development and Standards Support, Current Projects, Connected Vehicle Pooled Fund Study: Program to Support the Development and Deployment of Infrastructure Based Connected Vehicle Applications, 2017.
http://www.cts.virginia.edu/cvpfs_research/ (scroll down to see the project title)
As this web site indicates, "The goals of this project are to develop a Basic Infrastructure Message (BIM); and to establish a means to collaborate with the relevant standards development organizations. While the standards (such as SAE J2735) of various messages for DSRC equipped vehicles are fairly well defined, from the infrastructure side, which infrastructure information will be or needs to be broadcasted is relatively unknown and has not been well investigated yet. With this, it is needed to develop a corollary message from the infrastructure, a Basic Infrastructure Message (BIM). Having a standard BIM would help the OEMs and third party application providers to understand that there will be some infrastructure for them to rely on, and will give them some basis for the kind of message they can expect from the infrastructure. In addition, this will also help the public transportation agencies to know what kind of information to broadcast from their Road Side Equipment (RSE)."

See page 27 of this report for more information about the principal investigator for this project, Michael Brown of Southwest Research Institute.

State Research Efforts

The following presents brief summaries of the research conducted in areas related to Caltrans' interest in in-vehicle safety warnings by state DOTs or other transportation-related organizations in these states:

- Iowa.
- Michigan.
- Minnesota.
- Texas.
- Wyoming.

Iowa (Automated Vehicle Technologies Project)

Contacts: Scott Marler, Director, Office of Traffic Operations, Iowa Department of Transportation, 515-239-1040, scott.marler@iowadot.us.

Donna Matulac, Senior Transportation Engineer, Office of Traffic Operations, Iowa Department of Transportation, 515-239-1192, donna.matulac@iowadot.us.

S. Sinclair Stolle, Traffic Management Systems Engineer, Office of Traffic Operations, Iowa Department of Transportation, 515-239-1933, sinclair.stolle@iowadot.us.

A recent interview with Iowa DOT staff from the agency's Office of Traffic Operations centered on Iowa DOT's Automated Vehicle Technologies Project, which began in 2016 with the development of a custom vehicle to test and ingest data for multiple "use cases" (types of information that can be ingested to appear on an in-dash display), including:

- Crash.
- Work zones.

- Weather.
- Obstacle.
- Wide moving jam.
- Event congestion.

The conceptualized system has two key components:

- High-definition (HD)/3-D cloud-based digital mapping of paved roads with centimeter-level accuracy that is ingested by the vehicle.
- Predictive travel modeling and validation that is also ingested by the vehicle.

The new technology is expected to work in all weather conditions; predict anticipated traffic and roadway conditions; communicate seamlessly with other automated vehicles; and use HD mapping for precise vehicle location.

Current Research Efforts

The project team is focusing on three use cases in its initial testing: work zones, weather and wide moving jam. Sinclair Stolle and Donna Matulac, project team members, reported that vehicle testing is anticipated to begin in the next six to seven months, with interim testing beginning this fall. Data used for the project will be processed through the cloud using HERE's HD Live Map. (See Related Resources below for information about HERE, an Iowa DOT partner.)

Among the issues the project team is evaluating is whether the right alert is delivered at the right time. The project team will begin with smartphone application development to assess the quality of the data and alerts, and move on to the in-dash display of alerts. (A new test vehicle that will allow for testing of the in-dash display will be completed in the next six months.) Alerts generated for testing will provide both audible and visual cues, similar to commercial navigation applications. Stolle pointed to the audible cue generated in Iowa DOT's 511 app as an example of an audible cue in the test environment. The new 511 "Tell Me" feature "allows people to get hands-free, eyes-free audio notifications of traffic events while driving." The "Tell Me" feature also has an "I'm a driver" or "I'm not a driver" option; the "I'm a driver" option allows the driver to open the app to check on traffic events before starting to drive; the "I'm not a driver" option lets passengers take control of the device. (See Related Resources below for a blog post about the 511 mobile app update.)

The project team will begin with an examination of hazard alerts associated with work zones and then move on to wide moving jams (slowed traffic ahead due to incidents that have an "accordion effect" on traffic). Also expected this fall is the issuance of a request for proposal to identify a vendor to manage the project's data feed.

Managing Data

Stolle and Matulac noted the significance of data quality and formatting, and indicated that this spring's proof-of-concept testing highlighted the need for more accurate data. While the data are appropriate for use in connection with the agency's 511 system and for traffic management, the same data sets are not accurate enough for use in connection with an automated vehicle. The team has asked its partner, HERE, to investigate the lack of data standards with regard to data quality and format.

What's Next

A small proof of concept was conducted this summer using the HERE application, DOT data and DOT employee testers. A larger-scale pilot, to be conducted this fall, will use paid participants from outside the agency.

Related Resources

Automated Vehicle Technologies Project: Vision Document Final, Iowa Department of Transportation, March 2017.
https://www.iowadot.gov/pdf_files/IowaVisionDocument.pdf
Among the elements of Iowa DOT's automated vehicle project is a real-time vehicle to vehicle/infrastructure (V2X) hazard alerting system for crashes, weather, work zones, obstacles, traffic jams and special events. This document describes the use cases along with the research and development needed to prepare for and support eventual deployment.

The hazard alerting element of this project appears to be most relevant to Caltrans' interests; page 19 of the report (page 22 of the PDF) includes this description:

> *V2X Hazard Alerting.* This work will show that datafeeds can be successfully ingested by the Data Platform, and that appropriate hazard alerts can be generated by the platform, intelligently distributed to and received by test devices. Test devices will include both smartphones and an in-vehicle dashboard display.

Page 20 of the report (page 23 of the PDF) identifies these three key activities planned for 2017:

- V2X Hazard Alerting to smartphones. A proof of concept will confirm that specific datafeeds from the DOT and HERE can successfully be processed through the cloud platform and provided to a smartphone. A pilot is also planned to collect feedback from a limited number of users in a real-world setting, to inform further testing and plans for later wide-scale deployment.
- V2X Hazard Alerting to an in-vehicle dashboard display. This proof of concept is planned to show that specific datafeeds from the DOT and HERE can successfully be processed through the cloud platform and provided to an in-vehicle display.
- V2X Hazard Alerting and AV-Ready Datafeeds to support partial automated vehicle control on predetermined routes. This proof of concept is planned to show that specific datafeeds can be ingested by a research vehicle and used as sensor inputs to the vehicle control system for specific automated driving functions.

> Each of these activities will work with a subset of the overall driving environment data to explore how specific use cases might function (e.g., work zone data and HD map data). This work is in its early stages and may evolve as the Team learns from its efforts.

"Automated Vehicle Testing," Sandra Larson, Iowa Department of Transportation, March 2017.
https://iowadot.gov/systems_planning/freight/FAC/FAC_AutomatedVehicleTesting_030317.pdf
This presentation summarizes the agency's Automated Vehicle Technologies Project. Among the project's goals are to define the right data and common standards, and then share useful data with others.

"HERE Unveils HD Live Map, Creates Commercial Path to Highly Automated Driving," Press Release, HERE, January 2016.
https://here.com/en/company/newsroom/press-releases/2017-10-01-1
From the press release: HD Live Map is an integrated offering, consisting of multiple layers of data delivered in a map-tile format. It is designed to enhance both Advanced Driver Assistance Systems (ADAS) and automated driving functionality, and therefore make driving more comfortable and enjoyable.

HD Live Map includes data which tends to have high permanency, such as lane level information; data which is temporal in nature, such as road construction, traffic and accidents; and analytics data, including speed profile information that informs the vehicle about how to drive based on actual human behavior data.

"New Options for 511 are Geared to Keep Travelers Safer on the Road This Winter," Blog Post, *Transportation Matters for Iowa*, Iowa Department of Transportation, October 2016.
http://www.transportationmatters.iowadot.gov/2016/10/new-options-for-511-are-geared-to-keep-travelers-safer-on-the-road-this-winter.html
From the blog post: The Iowa 511 mobile app update will more easily inform drivers of Iowa's road conditions without having to look at their smartphones. Included in the update is the "Tell Me" feature. This feature allows people to get hands-free, eyes-free audio notifications of traffic events while driving. Previously, users had to interact with the app in order to view details about traffic impacts they might encounter on their journey. "Traveler safety is our top priority, and the audio notifications will allow drivers behind the wheel to pay attention to the road and not become distracted by their devices," said Sinclair Stolle, traveler information program engineer at the Iowa DOT. The feature also has an "I'm a driver" or "I'm not a driver" option so passengers can opt to take charge of the device or allow drivers to check on their drive before they leave.

"This hands-free, eyes-free app update is important for drivers because it will allow them to open the app before they start driving, select that they are a driver and just drive," said Stolle. "The app will announce construction, crashes, or other things happening on the road ahead of them."

Michigan (Wx-TINFO System)

Contact: Steve Cook, Engineer of Operations and Maintenance, Michigan Department of Transportation, 517-636-4094, cooks9@michigan.gov.

In a recent interview, Steve Cook, engineer, Operations and Maintenance, Michigan DOT, noted that the agency has not developed or deployed an in-vehicle messaging and warning system of the type envisioned by Caltrans, though Michigan DOT does provide in-vehicle parking availability messaging to limited commercial vehicles as part of its Truck Smart Parking Services initiative. The agency has also demonstrated motorist advisories and warnings through an FHWA grant. This 2015 research used a cellphone application tied to the agency's Mi Drive traveler information web site to generate weather-related warnings. (See Related Resources below for the Wx-TINFO system developed in this research.) As Cook noted, beyond those efforts, the agency "ha[s]n't fully explored the heads-up displays and/or in-vehicle warnings to drivers."

Related Resources

Connected and Automated Vehicles and New Technology White Paper, Michigan Department of Transportation, July 2016.
https://www.michigan.gov/documents/mdot/2040_SLRP_CAV_NewTech_readyforweb_40816_521014_7.pdf
From the white paper: This white paper provides summaries of a few of the exciting advancements MDOT has made in fostering new transportation technology. The department is preparing for the potentially paradigm-shifting technologies of connected and automated vehicles (CAV) that have the potential to provide the citizens of Michigan with safer and more efficiently managed roads. In addition, advancements in operations and intelligent transportation systems (ITS) have already created a safer and more efficient transportation network, ensuring the effective movement of goods and people around the state.

Michigan Department of Transportation (MDOT) Weather Responsive Traveler Information (Wx-TINFO) System—Final Report, Christopher Toth, Michael Waisley, Jeremy Schroeder, Murat Omay, Collin Castle and Steve Cook, Federal Highway Administration, January 2016.
https://ntl.bts.gov/lib/58000/58000/58015/FHWA-JPO-16-323.pdf
From the abstract: This report describes the system development, implementation and evaluation of a recently completed Weather Responsive Traffic Management (WRTM) project in Michigan by the Michigan Department of Transportation. The MDOT Weather Responsive Traveler Information (Wx-TINFO) system brings together near real-time weather and environmental information collected from fixed and mobile data sources. The system processes the weather data and provides automated weather alerts and DMS message recommendations to Transportation Operations Center (TOC) Operators. The goal of Wx-TINFO is to integrate multiple weather data sources into a collective program that provides more accurate, timely and effective messaging; thereby improving operating conditions during severe weather conditions.

Related Resource:

> **"Weather Response Traffic Information System (WxTINFO),"** Federal Highway Administration, Michigan Department of Transportation, Mixon Hill and University of Michigan Transportation Research Institute, undated.
> https://www.its.dot.gov/presentations/Road_Weather2014/10E%20Cook_WxTINFO.pdf
> This presentation about the Wx-TINFO project includes a process overview and the types of warnings generated.

Minnesota (Connected Vehicle Research)

Contact: Cory Johnson, ITS Program Engineer/Traffic Research Director, Minnesota Department of Transportation, 651-234-7062, coryj.johnson@state.mn.us.

In a recent interview, Cory Johnson, ITS program engineer/traffic research director, Minnesota DOT (MnDOT) noted that the agency has conducted connected vehicle research that examined elements of the application Caltrans envisions, including an examination of the human factors associated with in-vehicle warning systems. Johnson indicated that MnDOT would be interested in the type of warning system Caltrans envisions, and describes the agency's current connected

vehicle research as a “fluid environment.” Below is a summary of the research projects Johnson highlighted, followed by a sampling of MnDOT’s connected vehicle–related research.

Smartphone Application

A 2013 project that focused on a miles-based user fee (MBUF) also assessed the feasibility of using consumer devices for implementing connected vehicle and MBUF applications. Researchers used an in-vehicle system composed of entirely commercially available components, primarily a smartphone using an application capable of tracking participant vehicle trips.

Five hundred randomly selected drivers participated in the research project. Data from Wright County’s sign database were placed onto a smartphone platform for use during the research. Researchers developed a smartphone app that calculated the miles traveled and compared the driver’s location with data from the sign database and provided a smartphone warning of a school zone, curve ahead or other type of warning. The warning provided both audio and visual cues, with information appearing on the driver’s cellphone that looked much like the actual sign; an alert sounded that provided the audio cue. In addition to considering the effectiveness of the warnings, researchers examined the human factors associated with how these warnings were received—what worked best and how the subjects reacted. Researchers found that speed reduction signs were more effective when using the smartphone app. Johnson indicated that while research results were promising, more work was needed on the interface.

Johnson noted that the static sign database could be used for other projects to provide an alternative to the use of roadway signs. He sees the possibility of in-vehicle warnings replacing roadway signage when almost all vehicles are appropriately equipped. He provided this example of an effective use of in-vehicle warnings: When areas are flooded, an in-vehicle warning can alert drivers to the actual flooding instead of relying on a roadside sign that is for the most part not applicable and can be ignored by motorists. An in-vehicle warning has the benefit of generating a warning only when a threat or emergency situation is relevant.

Use of Dedicated Short Range Communications

Researchers have also examined the generation of a real-time message about the gap (space between vehicles arriving at an intersection) and delivering that message to vehicles via DSRC. This gap acceptance demonstration project was conducted in a rural area with 2G reception. An intersection was instrumented with sensors to gather data that was sent to a DRSC transmitter, which then presented a message to the vehicle about the gap using audio and visual cues.

Johnson highlighted the issue of data latency (the time it takes for data packets to be stored or retrieved) when dealing with an issue such as gap acceptance, when responses are measured in subseconds. For the demonstration project, sensor data from the instrumented intersection was not brought back to a central database, instead relying on roadside equipment. The developed system communicated with the vehicle 10 times per second. Johnson questioned whether the frequency needed for real-time communication with vehicles could be provided when sending data back and forth to a central database for post-processing, or whether a roadside instrument that gathers and distributes the data would be required. Johnson noted that the level of responsiveness needed for a gap acceptance application may not be necessary for the less time-sensitive messages Caltrans is seeking to generate (fog appearing down the road, not a speeding car approaching an intersection).

Related Resources

Research in Progress: Development and Demonstration of a Cost Effective In-Vehicle Lane Departure and Advanced Curve Speed Warning System, Minnesota Department of Transportation, project start date: May 2016; expected completion date: August 2018.
Project description at
http://dotapp7.dot.state.mn.us/projectPages/pages/projectDetails.jsf?id=16005&type=CONTRACT
From the project summary: The proposed project would develop in-vehicle warnings, which could be deployed on a smartphone, to alert drivers ahead of curves that are deemed high risk. A goal of the study would determine how to appropriately capture the attention of potentially distracted drivers and reduce the speed of drivers approaching at dangerous speeds. Another priority would be to determine the distances ahead of the curves at which the warnings should be deployed to provide sufficient, but not preemptive, notice to allow drivers to safely reduce speeds. The study would incorporate naturalistic driving behavior data collected on rural Minnesota roads with known hazardous curves. This would provide information about the speed at which drivers tend to travel through curves and help identify the thresholds at which a warning may need to be displayed. The work would compliment other on-going work in Minnesota to develop a cloud-based Vehicle-to-Infrastructure repository of pertinent roadway information (e.g., work zone notifications and warnings), which could be communicated to drivers via their smartphones.

Connected Vehicles for Safety, Mobility and User Fees: Operations Summary Report for the Minnesota Road Fee Test Project, Ben Pierce, Minnesota Department of Transportation, February 2013.
http://www.dot.state.mn.us/mileagebaseduserfee/pdf/OperationsReportBattelle.pdf
From the abstract: The Minnesota Department of Transportation (MnDOT) organized a study to examine the implementation and operation of a mileage based user fee program (MBUF), which might allow for the supplementation or replacement of traditional gas taxes. The primary objectives of the study were to: assess the feasibility of using consumer devices for implementing Connected Vehicle and MBUF applications. These applications included localized in-vehicle signing for improving safety, especially for rural areas, and the demonstration of the proposed Connected Vehicle approach for providing location-specific traveler information and collecting vehicle probe data. The study consisted of 500 voluntary participants, equipped with an in-vehicle system comprised of entirely commercially available components, primarily a smartphone using an application capable of tracking participant vehicle trips. Successfully meeting its primary objectives, the system was capable of assigning variable mileage fees determined by user location or time of day, as well as presenting in-vehicle safety notifications which had measureable effect on the participants driving habits.

Connected Vehicles Program: Driver Performance and Distraction Evaluation for In-Vehicle Signing, Janet Creaser and Michael Manser, Minnesota Department of Transportation, March 2012.
http://www.its.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=1678
From the abstract: The Minnesota Department of Transportation (MnDOT) conducted a demonstration project as part of the Connected Vehicles Program to design, build and test three new software applications to run on a commercially available personal navigation device (PND). The goal of this study was to examine only the in-vehicle signing (IVS) function for four zones and determine the utility and potential distraction associated with this function. The specific zones of interest that were signed on the PND were areas where speed zone changes occurred along the same roadway or for speed changes associated with construction, school and curve

zones. A continuous navigation function was provided in two of the three conditions to examine the effect of navigation information alone and multiple sources of information on driving performance. Driving performance measures known to be related to distraction as well as subjective usability and workload measures were used to help identify potential distraction associated with the IVS information. The project identified some driver effects that may occur when using a commercially available navigation device with in-vehicle signing (IVS) information, such as drivers demonstrating higher speeds associated with some of the System On conditions. Overall, distraction effects were small and not consistent across all zones or conditions. The main conclusion drawn from this study was that the IVS information was considered useful by drivers and resulted in few distraction-related effects. The benefit of advance notification likely outweighs any distraction that may be associated with in-vehicle signing of these zones.

Cooperative Intersection Collision Avoidance System–Stop Sign Assist: Experiments to Validate Use of an In-Vehicle Interface Design, Ensar Becic, Michael Manser, Janet Creaser and Max Donath, Minnesota Department of Transportation, April 2012.
http://www.its.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=1712
From the abstract: The three studies included in the current report examine the transition from an infrastructure-based rural intersection crossing assist system to one located inside a vehicle. The primary goals of the first study, conducted in a simulator, were to examine the effect of potentially confounding factors, such as the drivers' familiarity with the assist system and the impact of cognitive load on the drivers' performance. Next, we examined the efficacy of several different designs of such system to determine the optimal interface design to be used for the in-vehicle system. Finally, the optimal design of the system was examined in the third study, as a field test. The results showed that the use of the system under cognitively demanding conditions did not result in any adverse consequences, which suggested that the processing of the system required minimal cognitive resources. Additionally, the results showed that the benefits of the assist system, such as reduced probability of accepting a critical gap were exhibited under the limited visibility conditions when the perceptual task of determining an appropriate crossing gap became overly demanding. The results from the field study showed that the use of the assist system resulted in improved intersection crossing performance exhibited in increased likelihood of making a complete stop at the stop sign and showed a strong trend toward a decreased probability of accepting critical gaps. Additionally, the impact of the in-vehicle CICAS-SSA [Cooperative Intersection Collision Avoidance System-Stop Sign Assist] was equivalent for older and younger drivers; that is, both age groups benefited from the use of the system.

Texas (Southwest Research Institute Research)

Contact: Michael Brown, Engineer, Southwest Research Institute, 210-522-3104, mabrown@swri.org.

Southwest Research Institute (SwRI) has been actively involved in ITS-related research since 1992. Many of SwRI's projects have focused on back-end systems that are outside the realm of interest for this project (parking schedules for airports, transit, commercial vehicles, truck packing and route restrictions, and commercial vehicle infrastructure integration). Below is a summary of a recent discussion with Michael Brown, engineer, SwRI Institute, which highlights elements of SwRI's research that may be of interest to Caltrans.

Dedicated Short Range Communications

Brown noted that DSRC can be an effective communication mechanism when two vehicles meet each other in a rural setting. The technology offers high availability but low latency, and can be effective when used for localized messages such as queue warnings. Brown considers DSRC the near-term solution for in-vehicle communication, though over time he expects systems will use other communication mechanisms.

Cellular Communications

If there is more time to deliver a message (such as notifying drivers of a construction site far ahead), Brown suggested using other methods such as cellular communication or Waze, a community-based traffic and navigation mobile app used by motorists to share real-time traffic and road information. Florida DOT, he said, is among the transportation agencies partnering with Waze to share data (see Related Resources below for more information).

Brown contrasted the Waze approach of drivers sharing real-time traffic and road information with state DOTs' need to gather and share high-quality data housed in an agency's traffic management system to deliver warning messages to drivers. The data associated with traffic management operations, he said, will be of higher quality and more timely than the data available through commercial vendors.

Related Resource

"The Waze Connection," Gene Glotzbach, *Sunguide Disseminator*, Florida Department of Transportation, August 2014.
http://www.fdot.gov/traffic/Newsletters/2014/2014-Aug.pdf
This newsletter article discusses Florida DOT's agreement to share information with Waze, including Florida DOT's access to the data Waze collects and the access provided to Waze to the third-party data feed from Florida DOT's 511 system.

Wyoming (Connected Vehicle Pilot Deployment Program)

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Connected Vehicle Pilot Deployment Program

FHWA contacts directed us to Wyoming DOT and the agency's Connected Vehicle Pilot Deployment Program, which makes use of integrated ITS data for traveler alerts, including in rural areas. In 2015, Wyoming was selected by the U.S. DOT as one of three locations (along with New York City and Tampa, Florida) to test and deploy advanced DSRC technology to improve safety and mobility. In Wyoming, this technology will be used to improve monitoring and reporting of road conditions to vehicles on Interstate 80 (I-80).

Wyoming DOT will use vehicle-to-vehicle (V2V), V2I, and infrastructure-to-vehicle (I2V) connectivity in its connected vehicle pilot. Vince Garcia, program manager, GIS/ITS Program,

Wyoming DOT, reported that the DOT "is planning to deliver real-time information associated with incidents, construction, variable speed limits, road conditions and more (in the future) via a TMDD [Traffic Management Data Dictionary] v3.03c data feed." The agency has identified at least one unspecified partner willing to make this information available via the partner's in-vehicle navigation system. Similar information will be available via the connected vehicle operational data environment. Garcia also indicated that Sirius XM may pick up Wyoming DOT's data via this feed.

Technology

The project's web site (https://wydotcvp.wyoroad.info/) describes the technology employed in the pilot program:

- *Roadside units*. The 75 units installed along sections of I-80 identified as "hot spots" will receive and broadcast messages using DSRC technology.
- *Instrumented field vehicles*. Four hundred vehicles (both fleet vehicles and commercial heavy trucks) are equipped with DSRC-connected onboard units that "broadcast basic safety messages, share alerts and advisories, and collect environmental data through mobile weather sensors." Wyoming DOT sought "a diversity of trucking firms to participate in the pilot starting with small local firms to large national carriers."
- *Traveler information*. Data collected by the instrumented vehicles and the roadside units will be used to provide improved travel information to motorists through the Wyoming 511 app, the commercial vehicle operator portal (CVOP) and other services. (The CVOP is described as a "one-way interface [that] provides updates from the Wyoming CV system to an online portal for freight stakeholders. The portal will include current and forecast road condition information with a commercial vehicle operator focus.")

A sample of the TMDD v3.03c data feed is available in Attachment A. This information is provided through a representational state transfer (REST) endpoint that presents the file in JavaScript object notation (JSON) format.

Warning Types

The Wyoming DOT pilot system can generate several types of real-time warnings. From the project's web site:

- *Spot weather impact warning*. Enables localized road condition information, such as fog or icy roads, to be broadcast from a roadside unit and received by a connected vehicle.
- *Situational awareness*. Provides relevant road condition information including weather alerts, speed restrictions, vehicle restrictions, road conditions, incidents, parking and road closures. The information is broadcast from roadside units and received by the connected vehicle.
- *Work zone warning*. Communicates information to approaching vehicles about conditions at a work zone ahead. Approaching vehicles receive information about work zone activities or restriction information that could present unsafe conditions, such as obstructions in a vehicle's travel lane, lane closures, lane shifts, speed reductions or vehicles entering or exiting the work zone.

Project Schedule

Wyoming DOT's Connected Vehicle Pilot Deployment Program includes three phases:

- Phase 1 ended September 30, 2016. In this phase, developers "established the needs, developed concepts for the proposed system, developed performance criteria, and ensured the safety, security and privacy of participants."
- Phases 2 and 3 "will result in an operational CV system that generates meaningful travel alerts and advisories delivered with new communication techniques and have meaningful impacts on truck and passenger travel on the corridor of interest." A February 2017 fact sheet (see Related Resources below) provides a timeline for testing:

  > Testing will begin on WYDOT fleet vehicles (highway patrol vehicles, snowplows and other partner vehicles) in the fall/ winter of 2017 to 2018. The pilot will expand to testing with commercial vehicles in the fall/winter of 2018 to 2019.

Related Resources

Connected Vehicle Pilot Deployment Program: Wyoming, U.S. Department of Transportation, February 2017.
https://wydotcvp.wyoroad.info/assets/promotion/WyomingCVPilot_Factsheet_v2_020817.pdf
This fact sheet describes the Wyoming DOT pilot, including this description of project partners:

> To ensure a successful pilot, WYDOT has brought together a team of stakeholders including freight partners who will provide the equipped vehicles. Freight partners also include fleet dispatch centers who use existing WYDOT traveler information services (e.g., the commercial vehicle operator's portal). In addition, WYDOT is working closely with other stakeholders including trucking associations, other pilot sites, and the USDOT to ensure that the pilot deployment is interoperable and replicable in other parts of the country. WYDOT will also be supported by a technical team of subcontractors and vendors that will provide system development and integration services.

Connected Vehicle Pilot Deployment Program Phase 2, Data Management Plan—Wyoming, U.S. Department of Transportation, April 2017.
https://ntl.bts.gov/lib/61000/61700/61779/FHWA-JPO-17-470.pdf
This publication describes the data that will be collected and how it will be managed throughout the pilot project.

Page 6 of the report (page 15 of the PDF) describes the Wyoming CV System, which "includes the infrastructure used in the pilot and the back-office systems in charge of the various processes that lead to the generation and distribution of advisories and alerts for CV Pilot vehicles. The Wyoming CV System will be located at the WYDOT TMC. Additionally, this system provides external interfaces to share the advisories and alerts with the public and commercial vehicle operators."

The Wyoming CV System is composed of five subsystems:

- *Roadside units (RSUs)*. Deployed as part of the system along I-80. RSUs are physical units (fixed or portable) that include DSRC connectivity, application support, data storage and other support services to enable connected vehicle applications, such as necessary certificates.

- *Operational data environment (ODE)*. Receives information collected with connected devices, checks its quality and then shares it with other subsystems in charge of analyzing and distributing the information.
- *Pikalert system*. Supports the integration and fusion of connected vehicle and non-connected vehicle weather data to develop alerts and advisories about adverse weather conditions along I-80.
- *Data broker*. Receives information from the ODE, Pikalert and some external systems; analyzes the information; and shares it with the corresponding system or service, including other sources.
- *Data warehouse*. Stores various traffic management center- and connected vehicle-related data.

The report also provides more detail about the timing of Phases 2 and 3: Deployment is scheduled for the second phase (ending in April 2018) followed by an 18-month demonstration period in the third phase (starting in May 2018).

Connected Vehicle Pilot Deployment Concept Phase 1, Comprehensive Deployment Plan, ICF Wyoming, U.S. Department of Transportation, August 2016.
https://ntl.bts.gov/lib/60000/60700/60702/FHWA-JPO-16-297.pdf
The two-fold purpose of this document is described on page 3 of the report (page 12 of the PDF):

1. Summarize the Phase 1 activities in a way that presents a cohesive and comprehensive Phase 2 and 3 approach—what is proposed and how it will be accomplished. The CPDP [Comprehensive Pilot Deployment Plan], a required deliverable under Task 12, serves as a capstone document that brings together the iterative, stakeholder-driven process used in Phase 1 to conceptualize the system.
2. Describe how the WYDOT CV Pilot team will successfully deliver on the requirements defined in the Notice of Funding Opportunity (NOFO). This document serves as our application for the NOFO and meets the requirement for Volume I–Part I identified in the NOFO. Through the CPDP, WYDOT seeks to articulate our ability to deliver on the plans in Phase 1 by identifying and demonstrating that the partnership, the systems engineering, and the development approaches are apt for the task.

Connected Vehicle Pilot Deployment Program Phase 1, Concept of Operations (ConOps), ICF/Wyoming, U.S. Department of Transportation, December 2015.
https://ntl.bts.gov/lib/56000/56900/56997/FHWA-JPO-16-287.pdf
From the abstract: This document presents the concept of operations (ConOps) for the pilot program. The ConOps is a user-oriented document that describes system characteristics for a proposed system from the users' viewpoint. The ConOps has been drafted to communicate the users' needs for and expectations of the proposed system that utilizes vehicle to vehicle and vehicle to infrastructure connectivity to address adverse weather challenges along the I-80 corridor in Wyoming. The ConOps was developed through an intense process of stakeholder engagement and is consistent with the Connected Vehicle Reference Implementation Architecture (CVRIA). In general, the ConOps follows the template recommended by the IEEE Std 1362-1998 (R2007) but outputs from the Systems Engineering Tool for Intelligent Transportation (SET-IT) are included directly where appropriate. The ConOps will be the guiding document for subsequent planning activities in Phase I including security, safety, human-use and performance management plan development.

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