California and Oregon Advanced Transportation Systems (COATS) Phase 5: Final Report

by

David Veneziano, Ph.D.
Research Scientist II

Douglas Galarus
Program Manager
Systems Engineering Development and Integration Program

And

Leann Koon
Research Associate

Western Transportation Institute

College of Engineering

Montana State University

A report prepared for the

for the

State of California, Department of Transportation

Division of Research and Innovation

and

U.S. Department of Transportation

Research and Innovative Technology Administration

August, 2014

DISCLAIMER

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the California Department of Transportation (Caltrans) or Montana State University. This document does not constitute a standard, specification or regulation. It is not intended to replace existing Caltrans mandatory or advisory standards, nor the exercise of engineering judgment by licensed professionals. The document is a summary of an overall research effort sponsored by Caltrans.

Alternative accessible formats of this document will be provided upon request. Persons with disabilities who need an alternative accessible format of this information, or who require some other reasonable accommodation to participate, should contact Carla Little, Research Writer, Western Transportation Institute, Montana State University, PO Box 174250, Bozeman, MT 59717-4250, telephone number 406- 994-6431, e-mail: clittle@coe.montana.edu.

ACKNOWLEDGEMENTS

The authors wish to thank the California Department of Transportation (Caltrans) and the University Transportation Centers Program of the Office of Research, Development and Technology, Research & Innovative Technology Administration at the U.S. Department of Transportation for the funding of this research. The authors wish to thank the project steering committee, specifically Sean Campbell, Ian Turnbull and Ed Lamkin of Caltrans, Galen McGill of the Oregon Department of Transportation, Ron Vessey and Ted Bailey of the Washington State Department of Transportation and Jon Dickinson and Tom Moore of the Nevada Department of Transportation for their assistance and oversight.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This document summarizes the work completed for continued Intelligent Transportation Systems (ITS) demonstration, evaluation and technology transfer in rural northern California and southern Oregon. This work was completed under the fifth phase (Phase 5) of the California and Oregon Advanced Transportation Systems (COATS) project. The purpose of the overall COATS effort has been and continues to be encouraging regional, public and private sector cooperation between California and Oregon organizations to better facilitate the planning and implementation of ITS in a rural bi-state area extending between Eugene, Oregon and Redding, California. As COATS has matured, it, as well as projects which have spun off from the effort, have gained interest from surrounding states, specifically Washington and Nevada. Consequently, the COATS region is now the Western States Rural Transportation Consortium (WSRTC), which includes California, Oregon, Washington and Nevada. Although future research efforts will be conducted under the umbrella of the WSRTC, the work discussed in this document was conducted under the COATS umbrella and is discussed as such.

COATS Phase 5 activities included the Western States Forum and other general technology transfer activities, identification of Bluetooth reader deployment sites for future evaluation, a survey of automated safety warning devices and development of a regional ICM planning process. The Western States Forum served as a technology transfer platform where informative, in-depth technical presentations could be given by rural ITS practitioners. Presenters delved into how solutions were developed, focusing on applications that have been deployed in the field and are being used in live traffic situations. Success stories have been shared along with failures and problems so participants could learn what does and doesn’t work and why. The Forum has included live demonstrations of rural ITS technologies and “hands-on” question and answer periods. Participants have brought actual ITS equipment and performed informal “show and tell” sessions during the breaks.

The chain-up delay tracking project identified the number and location of sites needed to provide sufficient data to accurately determine delay. A future continuation of that work will deploy Bluetooth devices at these locations to collect data in support of the development of algorithms to estimate the delays occurring at chain-up areas. Work completed on a survey of safety warning devices identified ice, wind, visibility and general weather, animal-vehicle crashes, curve speed warning, slowed and stopped traffic or queuing, truck ramp occupancy, flood warning and other site-specific systems that have been deployed in the western U.S. The intent of the majority of these systems was to provide drivers with advanced warning of a hazardous condition so that the driver may be prepared when that condition is encountered, detour around the condition via other routes or halt the trip until it can resume safely. A key feature shared by these systems was that they were automated and self-contained in the field. The regional ICM planning work developed an overall framework for that process and then demonstrated how alternative routes to address ICM events could be identified. The demonstration of how alternative routes could be identified showed that comparable alternative routes could be identified in GIS that provide reasonable distance and travel times in the event that the study corridor was closed or had restricted traffic flow.

1. INTRODUCTION

The purpose of this document is to summarize the work completed for continued Intelligent Transportation Systems (ITS) demonstration, evaluation and technology transfer in rural northern California and southern Oregon. This work was completed under the fifth phase (Phase 5) of the California and Oregon Advanced Transportation Systems (COATS) project. The purpose of the overall COATS effort has been and continues to be encouraging regional, public and private sector cooperation between California and Oregon organizations to better facilitate the planning and implementation of ITS in a rural bi-state area extending between Eugene, Oregon and Redding, California.

As COATS has matured, it, as well as projects which have spun off from the effort (One Stop Shop (OSS), Integration of Aviation Automated Weather Observing System (AWOS) with Road Weather Information System (RWIS), Redding Responder, WeatherShare, Automated Safety Warning System Controller (ASWSC), etc.), have gained interest from surrounding states, specifically Washington and Nevada. This work has also generated interest based on being finalists and award winners for the following:

- One Stop Shop
    - 2014 Best of ITS (Awarded)
    - 2013 California Transportation Foundation Tranny awards (Finalist)
- Redding Responder
    - 2010 Best of Rural ITS Award (Awarded)
    - 2009 California Transportation Foundation Tranny awards Tranny (Finalist)
    - 2007 Best of ITS Award (Finalist)
- Automated Safety Warning System Controller
    - 2014 Best of Rural ITS Award (Finalist)
- Western States Rural Transportation Technology Implementers Forum
    - 2012 Best of Rural ITS Award (Awarded)

In light of this interest, COATS region evolved during the course of Phase 4 into the Western States Rural Transportation Consortium (WSRTC), which includes California, Oregon, Washington and Nevada. The WSRTC was established to facilitate and enhance safe, seamless travel throughout the western United States. The Consortium seeks to promote innovative partnerships, technologies and educational opportunities to meet these objectives. Additionally, the Consortium seeks to provide a collaborative mechanism to leverage research activities in a coordinated manner to respond to rural transportation issues among western states related to technology, operations and safety. Consequently, activities of the Consortium are focused on technology transfer/education (Western States Rural Transportation Technology Implementers Forum) and incubator projects (small scale research projects intended to serve as a "proof of concept" for larger subsequent efforts) centered on the Consortium pillars of technology, operations and safety. Although future research efforts will be conducted under the umbrella of the WSRTC, the work discussed in this document was conducted under the COATS umbrella and will be discussed as such.

1.1. COATS Vision

As part of the shift from COATS to the WSRTC, the vision of the group has been defined as follows: "The WSRTC shall promote innovative partnerships, technologies and educational opportunities to facilitate and enhance safe, seamless rural travel throughout the western United States." During the course of COATS Phase 5, the WSRTC vision has been employed in guiding the various efforts associated with the project.

1.2. COATS Mission

The COATS Project serves to focus member agencies on a seamless, state-of-the art, multi-modal transportation network benefiting travelers, goods movement, economic activity, and transportation systems operators in California, Nevada, Oregon and Washington. Collaboration between the COATS project and its partnership coalition provides information and serves to promote increased safety, mobility, traveler comfort, environmental quality, and operational efficiency and productivity. Again, as part of the shift from COATS to the WSRTC, the mission of this effort is presented as follows. "The WSRTC shall provide a collaborative mechanism to leverage research activities in a coordinated manner to respond to rural transportation issues among western states related to Technology, Operations and Safety." For this phase of COATS and all future phases, the mission of the WSRTC will be applied.

1.3. Phase 5 Goals

The primary goal of COATS Phase 5 was to provide research and support activities to help California and Oregon achieve the COATS vision. These activities included: promoting technology transfer, Bluetooth reader use in estimating chain-up area delays, synthesizing information on automated safety warning devices, and development of guidance for the planning of regional Integrated Corridor Management.

1.4. Project Tasks

The work plan for COATS Phase 5 consisted of the following nine tasks:

- Task 1: Project Management
- Task 2: Steering Committee Meetings
- Task 3: Western States Rural Transportation Technology Implementers Forum
- Task 4: Year 1 Incubator Projects
  - Synthesis of Automated Safety Warning Devices in the Western United States
  - Regional Integrated Corridor Management Planning
- Task 5: Year 2 Incubator Project
  - Chain-up Delay Tracking with Bluetooth
- Task 7: Outreach - conference presentations
- Task 8: Final Report
- Task 9: Workshop Presentation – in conjunction with Steering Committee meeting

Central to the project were the needs and interests of stakeholders within the COATS region. Their input was used to identify what activities would be pursued, as well as provide feedback and information in support of on-going work. WTI managed the project in consultation with the Project Manager and Steering Committee, to ensure integrity and unity in the project approach.

1.5. Report Organization

This report presents a summary of activities completed during Phase 5 of the COATS effort. Specifically, this report provides an overview of the major efforts of the project, including the Western States Forum and other general outreach and technology transfer activities, investigation of Bluetooth, Synthesis of Automated Safety Warning Devices in the Western U.S. and Regional Integrated Corridor Management Planning.

2. TECHNOLOGY TRANSFER

2.1. Western States Rural Transportation Technology Implementers Forum

The purpose of this project task was to provide financial and logistical support for the 2011, 2012, 2013, and 2014 Western States Rural Transportation Technology Implementers Forums. An event focused on delivering high quality technology transfer and networking opportunities, the Forum targets an audience of professionals working in design and maintenance of ITS technologies in rural environments. It is unique nationally with respect to its audience and technical content, and its origin and development reflect the idea of using COATS as an incubator for innovations in the use of technology to address rural transportation challenges.

The 2011-2014 Forums were all held at the Holiday Inn Express in Yreka, California. By virtue of its location near the Oregon border, this site facilitated participation from other states while remaining within Caltrans District 2, provided an economical site with necessary facilities, and put the attendees in close proximity through the duration of the Forum. To promote continuity, the Forum has been held the third week in June for the last two years.

Individual participation at the Forum indicates its growth and success. Starting with 15 in 2006, the 2013 Forum saw a record 45 participants. 2011, 2012 and 2014 had 31, 29 and 36 participants respectively. The Forum continues to attract a diverse audience. Participants in the last four Forums have come from seven different states (CA, ID, MT, NV, OR, TX, WA), with Texas being a new addition to the list of participant states. Along with the seven different states, attendees represented Caltrans Districts 1 through 10, several Caltrans divisions, five universities, the California Highway Patrol, a city public works department, the FHWA, the USDOT ITS Joint Program Office, and the Southwest Research Institute. It should be noted that while the Forum aims to maintain a smaller audience around 40-50 people, ongoing travel restrictions in California and other states have certainly impacted attendance numbers.

Each year, the Forum has been distinguished by informative, in-depth technical presentations and demonstrations given by a diverse group of rural ITS practitioners. Presenters have delved into how solutions were developed, focusing on applications that have been deployed in the field and are being used in live traffic situations. Success stories have been shared along with failures and problems so that participants learn not only what does work, but also what doesn't work and why. The extended length of the presentations (60-120 minutes) and the informal atmosphere have allowed frank discussion of equipment functionality, vendor claims, system performance, and other key information that practitioners need to know for successful rural ITS projects. The Committee has specifically encouraged presentations that discuss and/or demonstrate a project implemented or improved because of participation in a past Forum. For example, at the 2012 Forum the Nevada DOT demonstrated a mobile ITS hotspot trailer that they developed after seeing a similar trailer demonstrated by the Western Transportation Institute at a previous Forum. For specific presentation/demonstration topics, please refer to the yearly reports completed as part of this task (1, 2, 3, 4).

The Western States Forum website (www.westernstatesforum.org) has been maintained and the project continues to have a presence on the Western States Rural Transportation Consortium (WSRTC) website (www.westernstates.org). The Forum website includes a home page and individual pages that describe the Forum and its history and share pertinent information about the current Forum such as registration, lodging, maps and directions, and things to do around the

Forum location. Each past Forum has a set of pages that includes downloadable versions of the technical content and an image gallery. Contact information is also easily accessible.

To increase awareness of the Forum and its value, a one-page fact sheet that describes the Forum was updated, distributed, and posted on the Forum website as well as the WSRTC website. To build support for attendance, the Steering Committee also collected testimonials from past Forum attendees. The testimonials describe how knowledge gained at the Forum is being implemented in Caltrans districts and across the western states region. A one page hand out was created with this information which was also posted on the Forum and Consortium websites. Additionally, this information was compiled into a separate page on the Consortium website detailing how the Forum is effectively impacting change across the WSRTC region (http://www.westernstates.org/Impact/WSF/Default.html).

Announcements about the Call for Abstracts and Forum registration were posted on the ITS Rocky Mountain website and publicized in the Transportation Communications Newsletter (TCN). Additionally, prior to the 2013 Forum, the TCN's editor/publisher conducted a radio interview with Steering Committee members Ian Turnbull and Sean Campbell. The interview was included in an edition of the TCN and posted on the Consortium and Forum websites.

Participants repeatedly expressed a very high interest in attending a similar Forum the following year. Average evaluation ratings for quality, level of detail, relevancy and overall aspects of the Forum were consistently positive. Attendees appear to be satisfied with the length and general format of the Forum, including the small, focused group, detailed presentations, rural perspective, and excellent networking opportunities. The feedback suggests that the Forum is successfully meeting the needs of practitioners and the goals, mission and vision outlined for the Forum. For more detailed evaluation results for individual Forums, please refer to the yearly reports completed as part of this task (1, 2, 3, 4).

It should be noted that the Forum won the Best of Rural ITS Award for Best New Innovative Product, Service or Application at the 2012 National Rural ITS Conference. Steering Committee members described the unique aspects of the Forum and accepted the award on behalf of Caltrans and WTI.

2.2. Steering Committee Meetings

In addition to the technology transfer completed by the Forum, COATS/WSRTC Steering Committee meetings also provided an opportunity for discussion of current and future ITS activities in the region. Stakeholders were also able to meet and guide planning and decision-making related to the COATS project. The original proposal called for four Steering Committee meetings; during the course of the project, six meetings were held. In completing this task, three Steering Committee meetings were held in Yreka, California. These occurred on June 12, 2012, June 18, 2013, and June 17, 2014. Additionally, Steering Committee meetings were held on February 9, 2012 in Corvallis, Oregon (in conjunction with the Northwest Transportation Conference), September 19, 2012 in Biloxi, Mississippi (in conjunction with the National Rural ITS conference) and August 28, 2013 in St. Cloud, Minnesota (in conjunction with the National Rural ITS conference). Collectively, these meetings allowed for a discussion of the direction and focus of existing project tasks, presentation of initial and final task results, and discussion of future project directions.

Teleconferences were also held on an as needed basis. This allowed for a travel savings which could then be applied to other aspects of the work, specifically the Western States Forum, travel to local conferences, and the progress and results of the incubator projects discussed later in this document. Aside from the organization and conduct of these meetings, associated deliverables included meeting presentations, meeting minutes, and related website updates.

2.3. Outreach

Technology transfer outside of the ITS community is also important, and this subtask provided for travel costs and time for one WTI staff member to attend "local" transportation conferences. As discussed in the previous section, attendance at such meetings did occur, with presentations and a presence made at the annual National Rural ITS (NRITS) conference and the 2012 Northwest Transportation Conference in Corvallis, Oregon. This attendance was viewed as beneficial in creating new interest in COATS outside of California, where such interest remained strong. It also allowed for results of COATS/WSRTC projects to be disseminated to a wider audience of rural ITS professionals. The presentation at the 2012 Northwest Transportation Conference discussed the WSRTC and its activities, the 2012 NRITS presentation discussed the WSRTC and the efforts being made to address rural ITS challenges, while the 2013 NRITS presentation covered the results of the safety warning device synthesis incubator project (5, 6, 7).

3. CHAIN-UP DELAY TRACKING WITH BLUETOOTH

On northbound I-5 north of Redding, CA, when chain controls are in place, trucks are required to chain up near Fawndale. Figure 1 shows a map of the area and includes CCTV and CMS locations.

Figure 1: Map of I-5 near Fawndale (Source – One Stop Shop; http://oss.weathershare.org)

When these chain restrictions are in place, there can be a backup of trucks for 5 miles or more, all the way to Pine Grove, CA and beyond. In the four lane section near Fawndale the backup is one lane of trucks. Closer to Redding, there is a six lane section that develops a truck queue in the number two and three lanes. Determining accurate delay times that could be displayed on changeable message signs (CMS) before the backup starts may reduce the wait times and backup length, which could improve safety and reduce driver frustration within this corridor.

The intent of the project was to identify locations to deploy Bluetooth loggers and use the readings from these loggers in conjunction with chain control status to develop an algorithm to estimate travel time/delay through the affected area. The Bluetooth loggers would log as many events and as much normal traffic as possible. Camera images and chain control indications would also be logged to verify conditions. An iterative approach would then be used to develop a delay estimation algorithm based on the collected data.

3.1. Identification of Bluetooth Collection Sites

The thrust of the work completed for this incubator project was to identify the number and location of sites needed to provide sufficient data to accurately determine delay. For data transmission purposes the sites identified were located at Caltrans District 2 in conjunction with roadside CCTV or CMS locations. These and other Caltrans sites that had power and potential for RF data connectivity, such as light poles or nearby traffic signals, were also considered.

During the course of the work, an Excel file was developed that included detail on the prospective sites, including some comments and rationale for their selection. This also included a priority ranking for the selected sites. The idea behind the ranking is that the researchers could prioritize the deployment depending on how many sensors are available and viable. In general, at least two sensors would be necessary to do a Bluetooth deployment, but it was assumed that at least three and as many as eight devices could be available in the future when the deployment phase of the incubator project is pursued.

3.2. Recommendations

Based on the work completed, Table 1 was developed to present alternatives for future deployments during the data collection and analysis phase of the incubator project. The Fawndale CCTV site is ranked number 1 on the list, followed by Pit River Bridge CCTV site and the Riverside CCTV site. Alternately, the SR 44 CCTV site in Redding could be used as the third site. This is designated by 3' in the table, with the "prime" indicating alternate. Although only CCTV sites have been ranked highest, some of the remaining prospective sites are CMS or luminaire locations. Obviously communications would not be present at all locations, but it could be possible to service some of these sites during the course of the deployment phase of the incubator. That portion of the work will be carried out during the subsequent Phase of the COATS project.

Table 1: Recommended Bluetooth sites for chain-up tracking

Priority	Name	Area	Type	lat	lon	Elevation (ft)	Distance from Fawndale	Traffic Lane	Comments	Priority Reasoning	
										Positive	Negative
2	Pit River Brdg	Shasta Lake	CCTV	40.757574	-122.319179	1163	2.6	NB	dish	comm, determine delay end	
	Pit River Luminaire	Shasta Lake	Luminaire	40.753145	-122.321419	1195	1.8	NB		pole	no comm
1	Fawndale Rd	Fawndale	CCTV	40.730836	-122.320437	973	0.0	SB	dish	comm, location of interest	shorter detection range due to SB location, after lane closure
5'	Fawndale Rd	Fawndale	Luminaire	40.724468	-122.323994	926	0.5	NB	other luminaires in same area	determine delay & que length, pole	no comm
5	Fawndale Rd	Fawndale	Luminaire	40.719512	-122.328300	913	0.9	NB	other luminaires in same area	determine delay & que length, pole	no comm
6'	Old Oregon Trail	Mountain Gate	Luminaire	40.709976	-122.334307	864	1.6	NB			no comm
6	Old Oregon Trail	Mountain Gate	Luminaire	40.702829	-122.338737	864	2.2	NB		determine delay & que length, pole	no comm
	Cascade Blvd	Shasta Lake City	Overhead Sign	40.683147	-122.347547	785	3.6	SB			no comm, SB, relatively low
7	Shasta Dam Blvd	Shasta Lake City	Luminaire	40.679579	-122.348119	772	3.9	NB		determine delay & que length, pole for height	no comm
	Shasta Dam Blvd	Shasta Lake City	Overhead Sign	40.679457	-122.348588	768	3.9				
7'	Shasta Dam Blvd	Shasta Lake City	Luminaire	40.674442	-122.350208	755	4.2	NB			no comm
	Shasta Dam Blvd	Shasta Lake City	Road Sign	40.673489	-122.350711	755	4.3	NB			no comm, side of road, relatively low
4	Pine Grove Ave	Pine Grove	CCTV	40.663542	-122.355925	699	5.0	SB	dish	comm, determine delay & que length	shorter detection range due to SB location
4'	Pine Grove Ave	Pine Grove	CMS	40.663417	-122.355437	699	5.0	Overpass		best range/blocking location	no comm
8'	Oasis Rd	Redding	CMS	40.641515	-122.364831	667	6.6	Overpass		best range/blocking location	no comm
8	SR273	Redding	CCTV	40.630400	-122.369041	649	7.4	SB	dish, not on OSS	comm, determine delay & que length	shorter detection range due to SB location, probable city traffic influence
3'	SR44	Redding	CCTV	40.585071	-122.360535	577	10.6	Between lanes	dish, not on street view	comm, good location for range and to monitor only NB	city traffic
	Hartnell Ave	Redding	CCTV	40.563934	-122.359417	532	12.1	SB	no dish, not on street view, what kind of comm?	comm	shorter detection range due to SB location, city traffic
	South Bonnyview	Redding	CCTV	40.538300	-122.351334	499	13.9	SB	no dish	comm	shorter detection range due to SB location
	Smith Road	Redding	CMS	40.520044	-122.345063	455	15.2	Overpass		best range/blockage location	no comm,
3	Riverside Ave	Anderson	CCTV	40.468052	-122.307651	425	19.3	SB	dish	comm, before city, free flow	shorter detection range due to SB location

4. SAFETY WARNING DEVICE SURVEY

As Intelligent Transportation Systems (ITS) have evolved, several site-specific systems have been developed to address local safety and/or operational issues. Many are "self-contained," in other words, they collect localized metrological or traffic data, process it, and perform a specified task as a result, such as posting a warning message on a Changeable Message Sign (CMS). Such systems are typically roadside-based, with all equipment and processing completed on-site. These systems differ from those often employed in an urban setting, which are activated or receive inputs from a centralized Traffic Management Center (TMC).

While such self-contained safety warning systems exist throughout the western United States, there is a lack of documentation related to them, specifically an inventory of what is presently deployed. Tracking down the requisite information related to such widespread deployments is a challenge that cannot be easily completed by an entity in a time of limited budgets. However, the absence of such an inventory has prevented the opportunity for practitioners to learn about the deployments of a particular device in another location prior to pursuing their own. As a result, a synthesis of existing safety warning devices in the western U.S. was undertaken to address this knowledge gap. The synthesis documented where deployments were located, what their function/purpose was, and other information of interest. It provided practitioners with information to use in learning about the benefits of available systems, as well as a starting point for making contact with practitioners in other jurisdictions to learn more about their experiences with a system. The following sections summarize the results of the work. The final project report (8) contains further detail on the work completed during the course of this project.

4.1. Summary of Findings

During the course of the work, the researchers contacted agency staff in 12 western states to determine where automated safety warning systems existed. This effort yielded a significant amount of information on specific systems, as well as prospective contacts who could help to identify additional prospective systems. To this end, a total of 86 individual system deployments were identified. The states contacted and their respective number of systems are as follows:

- Alaska – 0
- Arizona - 5
- California - 26
- Colorado - 2
- Idaho - 1
- Montana - 3
- Nevada - 2
- New Mexico - 3
- Oregon - 16
- Utah - 5
- Washington - 16
- Wyoming - 7

The deployment types and the problems they targeted were quite diverse. The following types of systems were identified:

- Ice and weather warning – 11 systems

- Animal warning – 9 systems
- Curve warning (including speed) – 21 systems
- Traffic or queue warning – 8 systems
- Variable speed limits – 3 systems
- Wind warning – 7 systems
- Runaway truck ramp warning (in use) – 3 systems
- Flood warning - 4 systems
- Visibility warning – 6 systems
- Additional/general warning – 14 systems

As these figures indicate, a wide variety of systems were deployed across the western U.S. to address a number of different issues. The following subsections provide a summary of the key findings and observations that have been made based on the information documented during the work.

4.1.1. Ice and Weather Warning Systems

Ice and weather warning systems were one of the more common types of systems deployed. This is not surprising, given the wide range of weather conditions that exist across the varied terrain of the west. The majority of these systems target ice conditions, providing warning that ice is present on the pavement ahead. Remaining systems provided general warning of conditions that could be encountered ahead, typically snow storms. In most cases, the deployments were localized systems, although a limited number of systems covered a longer distance corridor. The shorter coverage of most systems is not surprising, as most deployments targeted a localized condition that was the result of terrain, foliage, microclimate or other factors.

The technologies and approaches to providing warning covered the entire spectrum, ranging from basic to complex. Some systems relied solely on RWIS station data, while many others used a complete suite of sensing technologies, including pavement sensors, to detect conditions. The approaches to warning included simple flashing beacons on static metal warning signs as well as messages provided by EMS signs. In most cases, a formal evaluation of the system and its effectiveness had not been made. In cases where an evaluation had been made, crashes had been reduced, as had vehicle speeds. When drivers were surveyed, they indicated that they had observed the message being presented by the system and had confidence in the system itself.

4.1.2. Animal Warning Systems

The animal warning systems documented were designed to provide drivers with notification that there are animals present in the vicinity of the roadside. The intent of this warning is to make drivers more aware of their surroundings and to be prepared for an animal to be in the road or potentially run out in the road ahead. The systems documented have typically been experimental in nature and many are now inactive. From the information provided by contacts, these systems typically cover a short segment or point of highway as opposed to a longer corridor. This is not surprising given that the costs of systems covering a long distance of highway would be prohibitively high, so systems focus on locations with a high concentration of animal-vehicle crashes or sites with consistent animal movement patterns. The detection technologies employed in the systems varied and included radio collars, infrared or laser beam detectors, body heat sensors, video detection and microwave detection. However, in spite of these technological approaches taken to detection, the warning provided to drivers was very basic, consisting of flashing beacons on static metal warning signs. In only one case was a portable VMS sign incorporated into the overall system.

4.1.3. Curve Warning Systems

Curve warning systems were the most frequently used systems identified during the work. The intent of these systems is simple: to provide drivers with a warning of an upcoming curve based on their current vehicle speed. The approaches used to alert the driver are varied, but the objective is to reduce curve-related crashes that are the result of speed. As expected, curve warning systems are located at point locations, although they tend to cover varied lengths of highway segments through a curve or curves. The technology used in detecting approaching vehicle speeds is primarily radar, although microwave vehicle detection was used in one system. Measured speed data is sent to a system controller which in most cases makes a determination of whether the vehicle is exceeding the posted speed limit for the curve. If a vehicle with excessive speed is detected, then the system takes an action. Some systems took a basic approach and activated flashing beacons on static metal warning signs. Other systems provided an electronic message to drivers via a CMS, DMS or EMS sign. Still other systems enhanced existing warning devices, incorporating flashing LEDs bordering chevron patterns to alert a driver to the presence of a curve.

4.1.4. Traffic and Queue Warning Systems

Traffic and queue warning systems were somewhat of a niche category; these systems targeted locations where sight distance or other local conditions can result in the need to provide warning to vehicles upstream that they should expect to encounter slowed or stopped vehicles ahead. The systems identified were used at locations where crashes have historically occurred as the result of drivers unexpectedly encountering traffic or queues. Most deployments have relied on loop detectors to determine vehicle presence and speed, although other technologies, such as general vehicle detectors or magnetometers, have also been used. Once the presence of a vehicle has been established by the system controller, a warning to drivers is activated. The approaches used in providing warning to drivers upstream include messages on CMS, DMS or EMS signs or a more basic warning via flashing beacons on static metal warning signs.

4.1.5. Variable Speed Limit Systems

Variable speed limit systems that are completely automated and do not require operator interaction from a traffic management center are limited. During the course of the work, three VSL systems were identified that are fully automated. Variable speed limit systems adjust speed limits based on prevailing traffic, weather and other conditions. The objective of such systems is to harmonize speeds and reduce crashes due to speed differentials. In the systems identified by the work, loop detectors, sidefire radar and general traffic sensors were used to detect current traffic conditions. Based on the data collected by these sensors, the system controller made adjustments to the posted speed limit to produce more harmonized traffic speeds. These speed limits were presented to drivers via digital variable speed limit signs, as well as by VMS signs in one case. The weather-based VSL identified during the work relied on RWIS data processed by the system controller to establish appropriate speed limits based on prevailing weather conditions in the vicinity of the station site.

4.1.6. Wind Warning Systems

Wind warning systems are basic in intent, seeking to provide warning to vehicles in general, or high profile vehicles in some specific cases, of high winds on an upcoming segment of roadway. When high winds are present, drivers are encouraged to stop and wait for the winds to die down, or to take an alternative route. The technologies used in developing these systems ranged from basic anemometers to complete RWIS stations. The primary data being measured were wind speeds and directions, which were used by the system controller to determine if wind gusts or sustained measurements exceed predetermined thresholds, set by an agency. When excessive winds are detected, the controller triggers the warning mechanism, which can be basic static metal warning signs with flashing beacons or specific messages provided by a DMS sign. All systems identified in this work incorporated flashing beacons and in two cases, highway advisory radio messages were also activated.

4.1.7. Runaway Truck Ramp Warning Systems

Runaway truck ramp systems are used to provide drivers of tractor-trailer combinations with warning that an upcoming runaway truck ramp (also referred to as an escape ramp) on a downgrade is occupied. This is critical information for the drivers of such vehicles that have lost their brakes on the downgrade and need to use such a ramp to bring their vehicle to a safe stop. It is of critical importance for a driver of a runaway vehicle to know whether the ramp is already occupied in order to avoid a secondary crash that could be catastrophic. The systems were generally straightforward in detecting vehicle presence, using loop or radar detectors or general sensors. Once a vehicle was detected, the system controller triggered a warning action, which ranged from simple flashing beacons on static metal signs to specific messages posted to DMS or EMS signs. Some systems also incorporated a CCTV camera that was triggered in advance to record the truck entering the ramp.

4.1.8. Flood Warning Systems

Flood warning systems provide warning to drivers that there is water over the roadway and that they should not proceed. These systems generally provided warning for a short segment of low lying roadway or at bridge locations. The mechanisms used to detect water presence or level were straightforward, relying on ultrasonic, radar or float sensors. When water was detected as present or having reached a certain threshold, the system controller activated the warning mechanisms, which in all cases were flashing beacons on static metal warning signs.

4.1.9. Visibility Warning Systems

Visibility warning systems generally function to provide drivers with a warning of reduced visibility ahead at certain locations that are subject to fog or dust conditions. By providing advanced warning of reduced visibility, the intent is to prevent initial and secondary crashes. Such systems have been used at point locations as well as along corridors. Visibility warning systems rely on visibility sensors or weather station equipment to establish that visibility distances have deteriorated. When reduced visibility is detected, the system controller activates CMS or DMS signs with specific warning messages based on visibility levels. One of the systems documented in this work took a simpler approach, relying on static metal signs and flashing beacons when visibility was reduced.

4.1.10. General Warning Systems

In addition to the systems already discussed in prior sections, other safety warning systems were identified during the course of the work. These systems have been grouped together as they provided warnings for specific conditions that did not necessarily occur with any frequency in other locations. Overlength vehicle detection systems have been deployed to address issues on corridors with restrictive curves where tractor trailer combinations meeting with ongoing traffic could present a safety issue. An earthquake warning system was used in Seattle to close the Alaska Way viaduct until it has been inspected for damage whenever a 3.0 or higher event on the Richter scale has been detected. Automated travel time systems were in use to provide drivers with an indication of the times required to reach different points on the road network. Overheight detection systems were used to provide warning that a vehicle's height will not clear an upcoming structure, typically a bridge. Downhill speed systems provided warning to heavy vehicles of an upcoming downgrade. Avalanche detection systems were used to determine when avalanches have potentially occurred. Finally, tunnel closure systems close tunnels in the event of an earthquake or fire to prevent drivers from becoming trapped.

4.2. Conclusions and Recommendations

A number of automated warning systems were identified during the work, including ice, wind, visibility and general weather, animal-vehicle crashes, curve speed warning, slowed and stopped traffic or queuing, truck ramp occupancy, flood warning and other site-specific systems. The intent of the majority of these systems was to provide drivers with advanced warning of a hazardous condition so that the driver may be prepared when that condition is encountered, detour around the condition via other routes or halt the trip until it can resume safely. A key feature shared by these systems was that they are automated and self-contained in the field. While these systems can be monitored (and overridden if needed) from a central location such as a TMC, they generally are left to operate in an automated fashion, detecting the condition in the field, determining that an action should be taken and them implementing that action.

In the majority of systems documented by this work, the components used in detection were basic. They typically included tried and proven sensors and other detection equipment to provide data to field controllers. When the field controller established that an action should be taken, warning was provided to drivers via basic and advanced mechanisms, ranging from flashing beacons on metal signs to electronically via CMS, DMS, EMS and VMS signs. Regardless of the approach taken, the intent to provide some form of warning was central to the majority of systems documented during the work.

In many cases, the systems documented in this synthesis were deployed in rural areas. This underscored two points. The first was that many rural safety problems can be addressed through ITS. The second point was that ITS systems are approaching a development stage where they are robust and reliable enough to be deployed in an automated fashion in a rural environment to address safety issues. These systems are still monitored from a TMC, but they have reached a point where monitoring is performed largely to ensure that the system is working as expected, not for activation purposes.

Based on the work completed, two recommendations could be made. First, the document developed by the work is intended to be a living document. As new automated warning systems are deployed across the western U.S. and come to the attention of the WSRTC and researchers, it is recommended that they be added to the document. Second, as part of being a living document, it is also advisable that this synthesis be updated on a periodic basis outside of individual systems proffered by contacts. A reasonable schedule for this effort would be on a four year basis, with the WSRTC steering committee directing the research team to undertake a revision and update of the current inventory of systems presented in this document.

5. ICM PLANNING

Integrated Corridor Management (ICM) seeks to coordinate individual network operations between parallel facilities/routes, in order to create an interconnected system allowing cross network travel management. Traditionally, efforts to address congestion have focused on the roadway system (freeways, arterials, etc.), rather than an integrated approach, including between modes. However, these individual system components often serve routes that are parallel to one another, forming a corridor linking the same origins and destinations. This has presented the opportunity for operating and optimizing the entire system, which is the goal of ICM. The resulting improvement in traveler movement reduces travel times and impacts to the collective system, while increasing the reliability and predictability of travel.

To date, limited work has been performed examining ICM in a rural/regional context. Based on this, there was an interest by the Western States Rural Transportation Consortium (WSRTC) in exploring regional ICM in greater detail. Specifically, there was interest in establishing guidance and criteria to initiate, plan and develop a regional ICM plan. This work defined what regional ICM is, established the factors to consider when developing a regional ICM plan, and developed protocols and criteria for ICM deployment in a regional context. These were then tested by developing a high-level regional ICM plan for two routes in the WSRTC region.

The work consisted of a literature review that examined existing ICM efforts and related research, corridor-planning efforts in the WSRTC region, summarized Emergency Operations Center protocols and plans in each of the Consortium states and a review of the United States Department of Transportation's ICM planning approach. This was followed by the development of the regional ICM planning approach and application of the general planning approach to identifying alternative corridors for a primary route impacted by an ICM. Based on this work, a series of conclusions and recommendations were then developed for future applications and research. The final project report (9) contains further detail on the work completed during the course of this project.

5.1. Literature Review

The literature review conducted in support of the work found that the primary focus of ICM initiatives and research to date has been on urban applications. In the limited cases where rural/regional ICM has been explored, efforts have focused on laying out a high-level approach to communications and emphasizing information sharing and dissemination. Neither the urban or rural discussions have established a process for the planning of an ICM effort. Corridor-related efforts in the WSRTC region have primarily focused on identifying potential issues that may impact the roadway system and addressing them cooperatively or through investments in improvements and technologies.

The primary conclusion that could be drawn from the literature review was that, while a good deal of work related to ICM had been completed, none of it had established a process that could be adapted for regional application. Furthermore, many of the aspects of work to date did not lend themselves to a regional usage. Consequently, the development of a process for planning regional ICM had to be developed from scratch. The approach would make use of the data that was presently available, recognizing that the collection and recording of additional data is not always feasible for a regional area covering multiple states.

Based on the review of existing Emergency Operations Center protocols and procedures, a basic framework to support decision-making and operations under a regional ICM operation had been established in each state. These protocols and procedures differed in some respects, but in general, they laid out a foundation for how operations would proceed when a regional ICM event occurred. The primary conclusion that could be drawn from this portion of the review was that there would be a need to develop a more coordinated set of protocols and interagency agreements between states/agencies to facilitate multi-state ICM operations. The development of such a coordinated set of protocols and procedures would be integrated into the overall regional ICM planning process as part of interagency agreements and related documents.

Finally, it was concluded that the USDOT's ICM planning approach had not yet been adequately defined in any document. Consequently, the approach developed for an urban context could not be transferred to a regional application. Based on this observation, those interested in ICM had some discretion in how to plan and implement it. In light of this, the development of an approach that was tailored to a regional context could be pursued.

5.2. Regional ICM Planning Process

The developed approach for regional ICM planning began with a group of entities/agencies identifying a need to address different events, conditions or scenarios that may occur along a primary corridor and may have a significant impact on mobility for an extended period of time. Stakeholders identified an initial series of events, conditions or scenarios that may have an impact on these routes and that ICM could help address at this initial point in the process. Once routes have been identified at a high level, the next step in the approach was to inventory existing highway assets and conditions. This would be done using Geographic Information Systems (GIS) data to identify alternative routes and establish whether they were suitable for use in a regional ICM setting. Following evaluation of GIS data and any resulting recommendations, the selection of alternate routes to be used during ICM events would be made by all agencies involved in the process. Steps following this point address more detailed development of documents and agreements. This includes the development of Interagency Agreements, as well as detailed Concept of Operations and Requirements documents. The final steps of the regional ICM planning process entail the development of deployment/operation protocols. The development of these documents and eventual deployment were not examined during the course of the work. Figure 2 presents a flowchart of the regional ICM planning process that was developed by the research.

5.3. Alternative Route Identification Process

Following the development of the regional ICM planning process, that process was demonstrated using GIS data to identify alternative routes to address general events. The general planning approach first identified study corridors/routes of interest and the conditions that could impact them. These routes and impacts were identified by the Steering Committee. The first corridor was U.S. 395 from Mojave, California to Carson City, Nevada, which could be impacted by construction, wildfires and perhaps volcanic activity. The second corridor was SR 299 – U.S. 395 from Arcata, California to the junction of U.S. 395 and U.S 20 in Oregon. This corridor could be affected by weather and wildfire activity. Based on these selected corridors, an inventory of highway assets along each was made using GIS data.

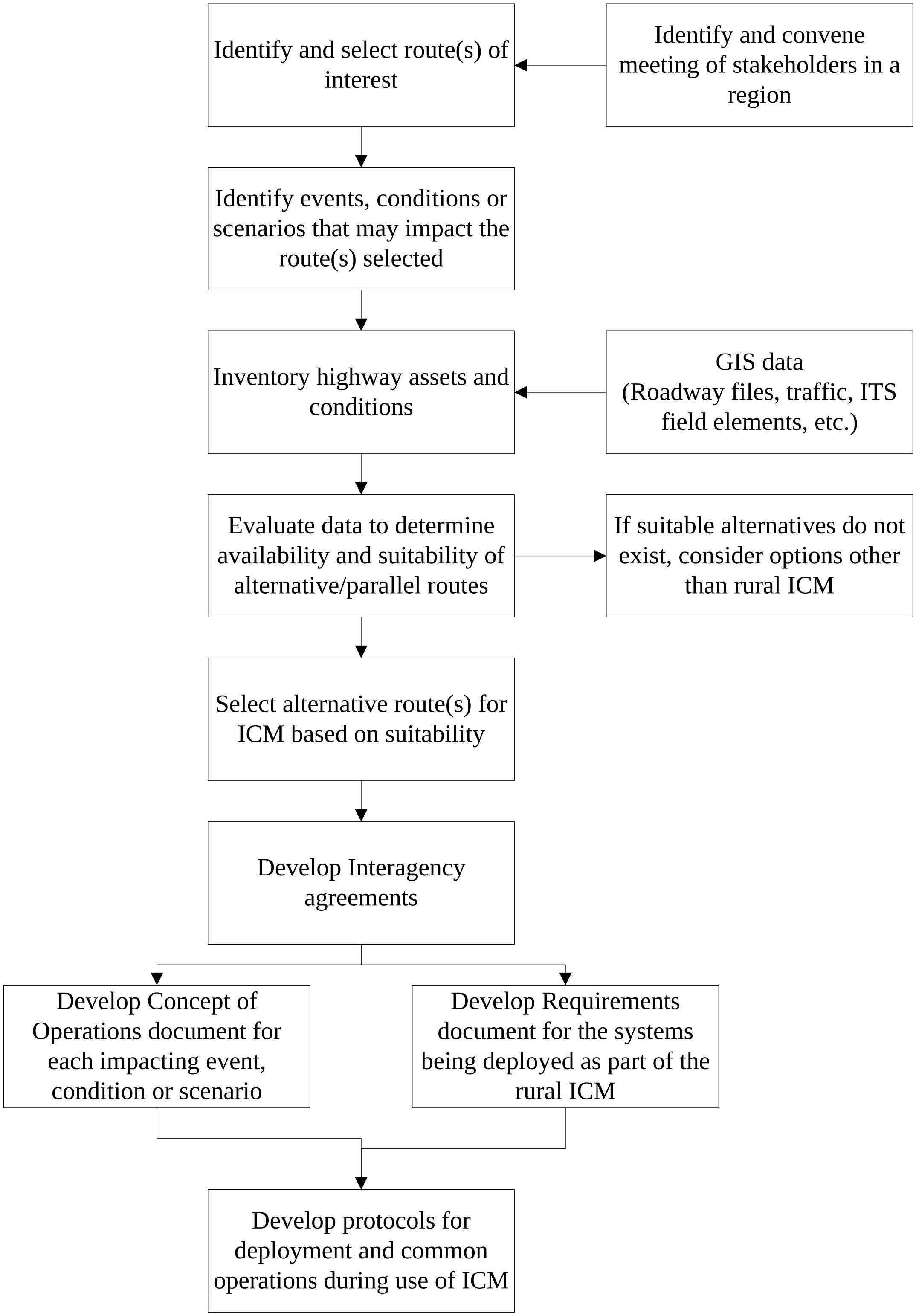

Figure 2: Flowchart of regional ICM planning process

GIS data used in the inventory and analysis consisted primarily of shapefiles from the Highway Performance Monitoring System, which provided information such as segment length, number of lanes, AADT and functional classification. Additional GIS data included the location of ITS elements along all roads in the study area, which was used to identify corridors where instrumentation was already present. Finally, National Bridge Inventory shapefile data was used to identify restrictions along segments when weight or height limits might be present. Once acquired, the data was formatted to present a unified dataset for analysis with the GIS platform.

Based on the route inventory, GIS route identification and optimization tools were used to determine alternative routes based on travel times, distance and capacity. The use of GIS in performing this task demonstrated its utility in evaluating road network data over a large geographic area in support of regional ICM planning activities. For the study cases examined, comparable alternative routes were identified in GIS that provided reasonable distance and travel times in the event that the study corridor was closed or had restricted traffic flow. The use of GIS allowed for different restrictions to be put into place not only on the primary corridor of interest, but also on other routes, segments or even regionally that might need to be excluded from consideration. The planning approach developed could provide a number of alternatives that would ultimately be presented to stakeholders for discussion and selection as part of the larger regional ICM planning process.

5.4. Conclusions and Recommendations

The work pursued by the regional ICM planning process developed an overall framework for that process and then demonstrated how alternative routes to address ICM events could be identified. The planning framework was developed from scratch, as past efforts and the U.S. DOT's ICM initiative did not present an approach that could be adapted to a rural environment. To that end, the approach that was developed was made with consideration of the unique characteristics and needs of a prospective ICM region. Such a region may cover multiple states, with the requisite differences in data availability and detail, and so forth. A demonstration of how alternative routes could be identified using data on a regional scale was made during the course of the work. This demonstration showed that comparable alternative routes could be identified in GIS that provide reasonable distance and travel times in the event that the study corridor was closed or had restricted traffic flow. Without a GIS platform to unify data from a large region and process that data to identify alternative routes, the overall regional ICM process would be more difficult to employ.

Based on the findings of the work, a number of recommendations have been made. First, the datasets employed in this work were limited to those that were readily available. The result of this was a less detailed dataset was used in the analysis than would have been the case if the planning effort was limited to within one state's borders. It is recommended that data such as geometric features and signal timing plans be investigated in future research and/or planning efforts. Second, the approach demonstrated relied on current information and trends (traffic levels). However, any potential ICM event will occur at some point in the future, and any future planning effort should incorporate future traffic projections developed from statewide (or in some cases within the overall region, urban-based) travel demand models. Finally, any pursuit of regional ICM planning in the future will need to extend beyond the planning phase discussed in this report and toward the development of interagency agreements and Concept of Operation and Requirements documents that allow for implementation to occur during an event. The content of those documents will rely on the event(s) and route alternatives identified during earlier planning steps.

6. CONCLUSION

This report has discussed the various activities during the COATS Phase 5 project. Phase 5 tasks focused on four specific areas: technology transfer, identification of Bluetooth reader deployment sites for future evaluation, a survey of automated safety warning devices and development of a regional ICM planning process. Technology transfer activities were centered on the growth and continuation of the annual Western States Forum. The identification of Bluetooth reader deployment locations will provide field data that will support the development of chain-up area delay time algorithms in a follow-up incubator project. The survey of automated safety warning devices has provided a synthesis of what systems have been deployed in the past, the components those systems have used, how they have performed and contact information for follow-up if a particular deployment is of interest to a practitioner. Finally, the development of a regional ICM planning process has provided a framework that can be employed by a group of stakeholders over a wide geographic area to identify alternative routes to address scenarios that impact a primary route.

6.1. Summary of Major Efforts

The COATS Phase 5 project, running between 2011 and 2014, focused on technology transfer, identification of future sites to deploy Bluetooth readers in support of determining chain-up area delays, a survey of automated safety warning devices and the development of a regional ICM planning process. The Western States Forum served as a technology transfer platform where informative, in-depth technical presentations could be given by rural ITS practitioners. Presenters delved into how solutions were developed, focusing on applications that have been deployed in the field and are being used in live traffic situations. Success stories have been shared along with failures and problems so participants could learn what does and doesn't work and why. The Forum has included live demonstrations of rural ITS technologies and "hands-on" question and answer periods. Participants have brought actual ITS equipment and performed informal "show and tell" sessions during the breaks. This event has continued under the scope of COATS Phase 6/Western States Rural Transportation Consortium and is expected to keep providing an intimate forum for the discussion of rural ITS applications, successes, and failures. In providing such a venue for ITS discussion, one of COATS' overriding goals was met: promoting technology transfer.

The incubator projects completed during the course of COATS Phase 5 provided information that is expected to contribute to the future development and deployment of systems and approaches that will benefit ITS in rural areas. The chain-up delay tracking project identified the number and location of sites needed to provide sufficient data to accurately determine delay. A future continuation of that work will deploy Bluetooth devices at these locations to collect data in support of the development of algorithms to estimate the delays occurring at chain-up areas. Work completed on a survey of safety warning devices identified ice, wind, visibility and general weather, animal-vehicle crashes, curve speed warning, slowed and stopped traffic or queuing, truck ramp occupancy, flood warning and other site-specific systems have been deployed in the western U.S. The intent of the majority of these systems was to provide drivers with advanced warning of a hazardous condition so that the driver may be prepared when that condition is encountered, detour around the condition via other routes or halt the trip until it can resume safely. A key feature shared by these systems was that they were automated and self-contained in the field. The regional ICM planning work developed an overall framework for that process and then demonstrated how alternative routes to address ICM events could be identified. The demonstration of how alternative routes could be identified showed that comparable alternative routes could be identified in GIS that provide reasonable distance and travel times in the event that the study corridor was closed or had restricted traffic flow.

6.2. Summary of Deliverables

During the course of the Phase 5 effort, a number of deliverables were produced. Specific report documents and memoranda are listed in the References section of this report (**Error! Bookmark not defined.**-9). In terms of deliverables produced over the course of the project, these included:

- Quarterly progress reports;
- Meeting minutes, meeting presentations (Steering Committee meetings and conference calls) which are posted on the Consortium website (http://www.westernstates.org/
    - Documents/Default.html);
- Organization and conduct of the Western States Rural Transportation Technology Implementers Forum from 2011 through 2014;
- Annual reports summarizing the Western States Rural Transportation Technology Implementers Forum (1, 2, 3, 4);
- Maintenance and expansion of the COATS (http://www.westernstates.org/Projects/COATS/Default.html), Western States Rural Transportation Consortium (http://www.westernstates.org/Default.html), and Western States Forum (http://www.westernstatesforum.org/) websites;
- Development, support and final documents associated with the "Survey of Western State Safety Warning Devices" project (http://www.westernstates.org/Projects/COATS/Documents/SafetyWarningSynthesis_2014_06_26_FINAL.pdf) (8);
- Development, support and final documents associated with the "Regional Integrated Corridor Management Planning" project (9);
- Development of recommended locations in support of Bluetooth device evaluation for measuring chain-up area delays;
- Conference presentations:
    - *The Western States Rural Transportation Consortium – A Partnership to Advance Rural ITS* - 2012 Northwest Transportation Conference (http://www.westernstates.org/Documents/WSRTC_PPT_NWTC_2012-02-09.pdf) (5);
    - *The Western States Rural Transportation Consortium – An Implementers Pooled-Fund to Tackle the Challenges of Rural ITS* - 2012 National Rural ITS Conference (http://www.westernstates.org/Documents/WSRTC%20Overview_2012%20NRITS_FINAL.pdf) (6);
    - *Synthesis of Western U.S. Automated Safety Warning Systems* - 2013 National Rural ITS Conference (http://www.westernstates.org/Documents/NRITS_Safety_Warning_Veneziano.pdf) (7);

7. REFERENCES

1 Koon, Leann A.F. Western States Rural Transportation Technology Implementers Forum: Review of 2011 Meeting. Western Transportation Institute, August 2011.

2 Koon, Leann A.F. Western States Rural Transportation Technology Implementers Forum: Review of 2012 Meeting. Western Transportation Institute, August 2012.

3 Koon, Leann A.F. Western States Rural Transportation Technology Implementers Forum: Review of 2013 Meeting. Western Transportation Institute, August 2013.

4 Koon, Leann A.F. Western States Rural Transportation Technology Implementers Forum: Review of 2014 Meeting. Western Transportation Institute, August 2014.

5 Veneziano, David, Doug Galarus, Ian Turnbull, Sean Campbell, Ted Bailey and Galen McGill. The Western States Rural Transportation Consortium – A Partnership to Advance Rural ITS. Presented at the 2012 Northwest Transportation Conference, Corvallis, Oregon. February 8, 2012.

6 Campbell, Sean, Galarus, Douglas, Ted Bailey, Leann Koon, Ian Turnbull, Galen McGill and David Veneziano. The Western States Rural Transportation Consortium – An Implementers Pooled-Fund to Tackle the Challenges of Rural ITS. Presented at the 2012 National Rural ITS Conference, Biloxi, Mississippi. September 17, 2012.

7 Sean Campbell, Leann Koon, Ian Turnbull and David Veneziano. Synthesis of Western U.S. Automated Safety Warning Systems. Presented at the 2013 National Rural ITS Conference, St. Cloud, Minnesota, August 28, 2013.

8 Veneziano, David and Leann Koon. Survey of Western State Safety Warning Devices. Western Transportation Institute, June, 2014.

9 Veneziano, David. Regional Integrated Corridor Management Planning: Final Report. Western Transportation Institute, August, 2014.