Survey of Western State Safety Warning Devices

A Project Completed for the California Oregon Advanced Transportation System (COATS) Project

Prepared by

David Veneziano Ph.D.
Research Scientist II

and

Leann Koon
Research Associate

Western Transportation Institute
Montana State University
PO Box 174250
Bozeman, MT 59717-4250

for the

State of California, Department of Transportation
Division of Research and Innovation

and

U.S. Department of Transportation
Research and Innovative Technology Administration

June, 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. The document is a summary of safety warning devices deployed throughout the western United States and has been developed as an informational resource for practitioners. The synopses of each system presented in the document reflect the notes kept by the authors during discussions with the various practitioners interviewed during the course of the work. Any discrepancies with respect to each system are the error of the authors and not the interviewee.

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.

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 may 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 funding this research. The authors also 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 of the Washington State Department of Transportation and Jon Dickinson of the Nevada Department of Transportation for their assistance and oversight. The authors also thank the numerous contacts from each state surveyed by this work. While too numerous to list here, they are identified in each of the specific case studies/deployments discussed in this document.

REVISION HISTORY

Version	Description	Date
1.0	Draft	February, 2014
2.0	Revised draft addressing steering committee comments	April 2014
3.0	Document finalized	June, 2014

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

CCTV – Closed Circuit Television

CMS – Changeable Message Sign

DMS – Dynamic Message Sign

DOT - Department of Transportation

EMS – Extinguishable Message Sign

HAR – Highway Advisory Radio

ICWS – Icy Curve Warning System

ITS - Intelligent Transportation Systems

LED –Light Emitting Diode

MP - Milepost

MPH – Miles Per Hour

MVDS - Microwave Vehicle Detection System

PM – Postmile

PTZ – Pan-tilt-zoom

RWIS – Road Weather Information System

SR – State Route

TMC - Traffic Management Center

VMS – Variable Message Sign

VSL – Variable Speed Limit

WSRTC - Western States Rural Transportation Consortium

EXECUTIVE SUMMARY

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 of this knowledge gap, the Western States Rural Transportation Consortium (WSRTC) has determined that a synthesis of existing safety warning devices in the western U.S. would be advantageous. This synthesis documents where those deployments are located, what their function/purpose is, and other information of interest. It provides 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.

For the purposes of this work, the research team documented systems in the following states: California, Oregon, Washington, Idaho, Nevada, Utah, Arizona, New Mexico, Colorado Wyoming, Montana and Alaska. The systems of interest to the work needed to be fully automated, i.e. the system would automatically detect a condition and trigger an action without any human interaction (ex. TMC monitoring and activation). Such systems could provide warning of ice on the roadway, the presence of traffic queues ahead, occupancy of runaway truck ramps, curve speed warning and so forth.

The approach used in documenting the systems was direct contact with personnel at various state and local transportation agencies in the states of interest via telephone calls. When the researchers spoke with contacts, they documented the data of interest for each system and used it to prepare the one-page summaries presented in this synthesis. The intent of the summaries was to provide the reader with the basic information on each system, such as its purpose, location, components, effectiveness and contact person.

During the course of this work, a significant amount of information on specific systems was obtained for a total of 86 system deployments. The deployment types and the problems they targeted were quite diverse. Among the types of systems deployed throughout the west were the following:

- 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

The intent of the majority of these systems is 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 their trip until it can resume safely. The feature that most of these systems share is 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 then 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-activated 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 this work.

While many of the staff members contacted during this work were satisfied with their respective systems and would use them again, some systems did present problems. This was particularly true of some weather-related systems, where detecting specific conditions such as icy pavement or low visibility can be a challenge. In these cases, the technologies employed were not yet capable of meeting the overall needs of the system or required careful consideration of sensor placement. Where such challenges were encountered, they have been documented in this synthesis. It is hoped that the lessons learned from such deployments will aid practitioners in developing and deploying new systems in the future while avoiding the pitfalls of the past.

1. INTRODUCTION

As Intelligent Transportation Systems (ITS) have evolved, several site-specific systems have been developed to address local safety and/or operational issues. For example, the California Department of Transportation (Caltrans) has deployed systems at specific locations to notify motorists of icy curves, provide road condition information for specific routes through standalone systems such as Highway Advisory Radios, or HAR (typically not automated), and address other concerns. The Montana Department of Transportation (MDT) had deployed an animal warning system along a stretch of roadway to alert motorists to animal presence, although it has since been removed. Similarly, state Departments of Transportation (DOTs) and local entities across the west have deployed various systems to address a number of different local concerns.

As stated, many of these systems are deployed to address a localized issue. As a result, 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. This is not surprising, as such systems may be deployed by a range of entities, from state DOTs down to counties and cities. 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. In essence, no one in the west really knows what deployments have been made in neighboring states (or even within their home state in some cases).

As a result of this knowledge gap, the Western States Rural Transportation Consortium (WSRTC) has determined that a synthesis of existing safety warning devices in the western U.S. would be advantageous. This synthesis would identify where existing deployments are located, what their function/purpose is, and other information of interest. Such a synthesis would entail contacting state DOTs, as well as local city and county personnel to determine what devices they presently have deployed in their jurisdiction. As a result of this work, practitioners will have a synthesis document available to them that presents information related to safety warning devices throughout the west. This information could then be used to learn about the benefits of available systems, as well as provide a starting point for making contact with practitioners in other jurisdictions to learn more about their experiences with a system.

1.1. Past Work

During the course of preparing this document, the team could find no significant, completed work similar in nature or scope to what is proposed here. Some experimental systems have been documented singularly as part of overall research efforts. Identifying and obtaining the documentation for these systems can represent a time-consuming effort for ITS practitioners whose duties extend well beyond such research efforts.

Additionally, only limited syntheses of active warning systems even exist in literature. The closest to a comprehensive synthesis has been performed by Sisiopiku and Elliot (1), which looked at active warning systems in general. Similarly, Robinson et al. documented ITS systems, both automated and operator-controlled, in rural areas (2). In each of these efforts the work occurred nearly one decade ago, before many automated systems came into use. In some cases, inventories specific to a certain type of system have also been pursued. For example, Abdel-Aty et al. compiled a synthesis of visibility detection systems as part of work for the Florida Department of Transportation (3). Murphy, et al. focused on systems that targeted road weather conditions and this effort encompassed systems beyond automated and operator-controlled safety warning (4). Decker, et al. focused on systems related to snow and avalanche events on low volume roads, specifically how to provide warning to maintenance staff and closures to stop motorists (5). The common issue with each of these documents is that they largely focused on synthesizing systems that had previously been reported in literature or that the researchers performed only a limited level of outreach to identify additional systems.

In light of these limited past efforts, it is clear that no comprehensive inventory of automated safety warning systems exists. This is true in general on a national scale, as well as specific to the western United States. In large part, this is the result of the disparate nature of the systems, which can be maintained by any number of entities ranging from state DOTs down to local communities. This distribution of systems presents a challenge in terms of identifying the proper contact that can discuss each system and coordinating the communications with that contact to obtain that information. However, the prospective lessons learned that these systems represent hold the potential to provide cost savings and improved success and reliability of future deployments, making efforts to obtain information about these warning systems a worthwhile endeavor.

1.2. Investigation Objective

The primary objective of the proposed work is to document automated safety warning devices that have been deployed across western states. For the purposes of this work, western states are defined as those west of the Rocky Mountains: California, Oregon, Washington, Idaho, Nevada, Utah, Arizona, New Mexico, Colorado, Wyoming, Montana and Alaska. The systems of interest to the work needed to be fully automated, i.e. the system would automatically detect a condition and trigger an action without any human interaction (such as TMC monitoring and activation). Such systems could provide warning of ice on the roadway, the presence of traffic queues ahead, occupancy of runaway truck ramps, curve speed warning and so forth. One exception is that radar speed signs were not documented as part of this effort. Such signs, which measure the speed of an approaching vehicle and post that speed to a digital board in conjunction with a static metal speed limit sign, are used extensively throughout the U.S. In light of this use, it would be impossible from a labor and budget standpoint to contact all prospective agencies (including all western towns, counties, and police forces) regarding their use of this warning device.

The researchers relied on the knowledge of each contact to establish whether a system was automated. In some cases, a system could have been indicated as being automated by some entities but not by others. For example, some contacts indicated that travel time systems were automated, while others did not. It is possible that similar systems in other locations were also automated in a similar manner but not viewed as being so by the contact that was interviewed. Consequently, such systems did not get documented by this work.

1.3. Approach

The approach for completing this research was straightforward. Once the items of interest for documentation were identified, the research team made direct contact with personnel at various state and local transportation agencies in the western states of interest. These contacts were identified by the WSRTC Steering Committee (ex. known contacts within their state, colleagues, etc.). Additionally, contacts maintained by the research team as part of Technology Transfer activities, namely the Western States Rural Transportation Technology Implementers Forum were also employed. The researchers made contact via telephone calls to ensure that a minimum of time input was required for those being interviewed. In general, discussions related to each system required five to seven minutes.

When the researchers spoke with these contacts, additional contact leads were requested. In this manner, the potential series of contacts branched out, from a few initially to dozens throughout the course of the research effort. As a result, it is believed that the prospective contacts for a majority of the automated warning systems in the western U.S. were reached during the course of the work. Of course, it is possible that some contacts and systems were not identified through this approach, and so the systems presented in this document represent a best effort in terms of documentation. The synthesis is considered a living document, and if future deployments are identified or new contacts reach out to the authors in the course of reviewing this report, additions will be made as needed.

Once information was collected from contacts, it was documented in the one-page summaries presented in this synthesis. The intent of the summaries was to provide the reader with the basic information on each system, such as its purpose, location, components, effectiveness and contact person. If more detailed information is of interest to readers, they are encouraged to reach out to the contact provided for each system.

1.4. Information Obtained

In speaking with contacts, the research team sought information on a number of different items of interest to the Steering Committee. Standard questions were developed and used by the researchers to ensure consistent information and responses were obtained. Specifically, the questions and information discussed during interviews included:

- System name/type
- How long has/was the system been deployed (approximate date, month/year)?
- Is the system active or inactive? If inactive, what approximate date was it removed? (Note, as used in this synthesis, the term inactive generally connotes a system has been removed.)
- What is the approximate location of the system using your agency's identification method (e.g., county, route, milepost)?
- Is the deployment located along a high (45 mph+) or low (< 45 mph) speed roadway facility and is the highway divided or undivided?
- What is the intended purpose of each system (i.e., what problem is it targeting)? Please briefly describe.

- Please provide a general description of how the system works. Also, please indicate in general terms the types of components that make up the system and how they work to provide the specific warning.
- How effective has the system been in meeting its intended purpose? This can include any general observations as well as specific, data-driven evaluations. Have any formal evaluations of the system been completed? If so, are the results available in a report or other documentation?
- Would your agency deploy this type of system again if the need arose? Why or why not? Would the same components be used again? If no, why not?
- Are there improvements or changes that could be made to the system?
- Do you have any additional thoughts on this system you would like to share?

Information provided by contacts to these questions was recorded on standardized data sheets. That information was later used to develop the one page synopsis of each system.

1.5. Summary of Findings

During the course of the work, the researchers found that the majority of contacts were eager to share their experiences with different systems. This included candid insights into what worked and what did not work with the system. Such information was viewed as critical in ensuring that future deployments could address prospective problems from the start in order to ensure improved reliability and effectiveness.

In general, the number of systems deployed in each state varied greatly. Some states, such as Alaska, Idaho and Montana, had none or only a limited number of deployments in the past and at present. In talking with contacts in these states, there was a general lack of comfort with systems being entirely automated given the geographic scope of these states and staff constraints. Other states, such as California, Oregon and Washington had a number of deployments that targeted various problems on the road network.

A total of 86 individual system deployments were identified during the course of this work. The following list provides the number of those systems deployed by state:

- 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

Not surprisingly, the larger, more populated states such as California, Oregon and Washington were home to a majority of the systems identified. More rural states, such as Montana, New Mexico and Wyoming had lower numbers of deployments.

The deployment types and the problems they targeted were quite diverse. Among the types of systems deployed throughout the west were the following:

- 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 this list indicates, curve warning systems, including warnings related to vehicle speeds while approaching, were the most popular systems in use. These systems were generally straightforward in terms of their approaches to detection and warning, which is likely one of the primary reasons for their popularity. Ice and weather systems were the second most popular type of warning system, which is not a surprise given the varied weather and resulting road conditions that are found throughout the western U.S. Animal warning systems were also common, although most of these were experimental and no longer active. Traffic/queue warning and wind warning systems also saw a fair amount of use based on localized needs. Remaining system types saw varied use and also focused on more localized issues and needs. The complexity of these systems varied, but in general focused on basic approaches to detect and provide warning.

As this overview indicates, a significant number of deployments have been made to address various safety issues throughout the western U.S. A significant number of the systems discussed in this text remain active, although some have been removed based on obsolescence or because they were experimental. Regardless of their current status, the purposes of each system and the approaches and components they used to address a respective problem should be of interest to the reader. The following chapter provides such detail on a deployment-specific basis. A more comprehensive summary of the overall findings generated from this work is presented at the conclusion to this synthesis.

1.6. Synthesis Organization

This synthesis is divided into three chapters. Chapter 1 has outlined the research problem and the approach taken to address it. Chapter 2 presents the synthesis of automated warning systems identified during the course of the work. The systems are presented by their general type or function, based on the list presented in the previous section. Finally, Chapter 3 presents a summary of the findings, including a high level presentation of the basics of each system in a table format.

2. SUMMARY OF FINDINGS

During the course of this work, the researchers contacted agency staff across the western U.S. 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 during the course of this work. These systems are deployed in the following states:

- 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 have been deployed across the western U.S. to address a number of different issues. The following sections provide a summary of the key findings and observations that have been made based on the information documented during the work.

2.1. 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. In most cases, the systems were recent deployments made during the 2000s, although a few systems were deployed in the 1980s and 1990s. Table 1 presents a summary of the different ice and weather warning systems identified during the work.

Table 1: Ice and Weather Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
Fredonyer West Summit Icy Curve Warning System	California	Lassen 36, postmiles 10.45 and 11.89	Detect icy conditions and provide warning to motorists.	Fall 2008	Active	Pavement sensors, RWIS, EMS, amber flashers, CCTV, communications, battery back-up	3+ mph drop in mean vehicle speeds during clear, cold and not dry conditions 18% reduction in crashes annually
Fredonyer East Summit Icy Curve Warning System	California	Lassen 36, postmiles 13.32 and 14.35	Detect icy conditions and provide warning to motorists.	Fall 2008	Active	Pavement sensors, RWIS, EMS, system contoller, CCTV, communications, battery back-up	3+ mph drop in mean vehicle speeds during clear, cold and not dry conditions 18% reduction in crashes annually
Spring Garden Icy Curve Warning System	California	Plumas 70, postmiles 50.07 and 51.64	Detect icy conditions and provide warning to motorists.	Dec. 2009	Active	Pavement sensors, RWIS, CMS, system controller, CCTV, communications, battery back-up	N/A
Butte Creek Ice Warning System	Oregon	OR 140, milepost 21.7 - 41.7	Provide warning of icy conditions on a mountainous road.	Nov. 2005	Active	Wind direction/speed, moisture, temperature, humidity/dew point, and pavement condition sensors, system controller, static warning signs with flashers	System appeared to produce reductions in vehicle speeds when beacons flashing. Surveys of drivers found awareness of signs and beacons and confidence in warning accuracy.
King County Road Weather Warning System	Washington	South 277th St. and South 272nd St. corridor, Kent and Auburn	Provide warning of icy road conditions on shaded roadway segment.	Spring, 2013	Active	Pavement temperature sensor, roadside thermometer, humidity sensor, central processing computer, extinguishable message signs	N/A
Road Weather Information System Warning System	Arizona	I-10, I-40, SR 93, SR 260/SR 377/SR 277 Junction, SR 264, SR 87	Provide automated notice to maintenance staff that conditions have deteriorated.	2006	Active	RWIS stations/components, central control computer.	N/A
Idaho Storm Warning System	Idaho	I-84 from mp 222 (Idaho) to mp 41 (Utah)	Address poor visibility crashes on I-84.	1993	Inactive	Visibility, weather and traffic sensors, system controller, variable message signs.	High wind - mean speed fell 23 percent (58.4 mph to 42.3 mph) High winds and precipitation - mean speeds fell 12 percent (47.0 mph to 41.2 mph) Snow covered and high wind - mean speeds fell (54.7 mph to 35.4 mph)
Carlin Tunnels Ice Warning System	Nevada	I-80, milepost 260	Provide warning to motorists of ice presence in tunnels.	1985	Active	In-pavement ice detection pucks, infrared grip sensors, system controller, static warning signs with flashing beacons	N/A
Nugget Canyon Ice Warning System	Wyoming	U.S. 30, milepost 34	Provide ice warning for curved bridge.	2000's	Active	RWIS, system controller, static metal signs with flashing beacons, solar power.	N/A
Piney Creek Ice Warning System	Wyoming	I-90 crossing of Piney Creek	Provide ice warning for interstate bridges.	2006	Active	Pavement pucks, air temperature sensors, system controller, static metal signs with flashing beacons.	N/A
Fish Creek Icy Bridge Detection and Warning System	Utah	I-70 crossing of Fish Creek, milepost 11.5	Provide ice warning for bridge.	2013	Active	RWIS station, system controller, CMS signs, wireless communications, solar power.	N/A

As the results of the table illustrate, ice and weather warning systems have been deployed by a number of states. 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.

2.2. Animal Warning Systems

The animal warning systems documented in this system vary widely in terms of their approaches to detection technologies. The purpose of these systems has been straightforward: 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. Most systems have not had a formal evaluation performed to determine their effectiveness. Table 2 presents a summary of the different animal warning systems identified during the work.

As the results indicate, a fair number of states have hosted at least one deployment. 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 animal-vehicle crashes typically occur in a central location based on animal movement patterns. All of the systems documented were made in the 2000s, likely the result of new detection technologies becoming available that are of interest from a testing perspective. 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. Even more interesting is that only one of the systems deployed has been formally evaluated to date. The results of that evaluation showed small reductions in speeds when the system was activated, but large drops in the number of animal-vehicle crashes that occurred. When surveyed, a high percentage of drivers reported recognition of the system.

Table 2: Animal Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
PATH/Fort Jones Animal Warning System	California	SR 3, postmiles 36.50 - 37.30	Provide deer warning to drivers	September, 2009	Inactive	Radar, system controller, LED signs	Mean speeds reduced from 58.3 mph to 53.1 mph when animals detected and warning signs illuminated
Sequim Animal Detection System	Washington	U.S. 101, mileposts 267 - 264	Provide elk warning to drivers	Fall 2000	Active	Radio collars applied to the lead cow, radio receivers, static warning signs with flashers	N/A
Wenatchee Animal Warning System	Washington	U.S. 97A milepost 206	Provide animal warning to drivers	2000	Inactive	Infrared beams to detect animal presence, system controller, static warning signs with flashers	N/A
Colville Animal Detection System	Washington	Highway 395, milepost 290	Provide animal warning to drivers	2000	Inactive	Two sets of laser detectors, system controller, static deer warning signs equipped with flashing beacons	N/A
Elk Crossing Warning System	Arizona	SR 260 east of Payson, Arizona	Provide drivers with warning of large animal crossing	2007	Active	Infrared sensors, system controllers, radio communications, static metal warning signs equipped with flashin beacons, portable variable message signs	N/A
Nugget Canyon Flashing Light Animal Sensing Host System	Wyoming	U.S. 30, milepost 30.5	Provide warning of large animals crossing the road	Dec. 2000	Inactive	Body heat sensors to detect animals, system controller, static metal warning signs equipped with flashing beacons	N/A
Animal Crossing Warning System	New Mexico	I-40 in Tijeras Canyon	Provide warning of animals crossing the road	2007	Active	Video detectors to detect animals, system controller, static metal warning signs equipped with flashing beacons	N/A
Roadway Animal Detection System	Montana	U.S. 191, milepost 28 – milepost 29	Provide warning of animals crossing the road	Nov. 2004	Inactive	Microwave detectors, system controller, static metal warning signs equipped with flashing beacons, solar power	Vehicle speeds reduced by 1.52 mph when warning beacons on Large mammal collisions 66.7 percent lower 96 percent of surveyed drivers noticed the system
State Route 333 Animal Warning System	New Mexico	SR 333 at I-40 underpass	Provide warning that animals may be crossing road in area of Interstate underpass	2007	Active	Video-based motion detectors, system controller, static metal signs with flashing beacons, radio transmitters	N/A

2.3. Curve Warning Systems

Curve warning systems were the most frequently used systems identified during this work. A total of 21 systems were identified, and it is likely that more are in the process of being designed and deployed. 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. The various systems identified by the work are presented in Table 3.

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 systems have all been deployed in the 2000s and largely remain active to date. 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, which varies based on the deployment. 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. This message could be a basic warning that simply provided a message such as "Slow Down" or a more customized message that included the vehicle's speed (e.g., "Your Speed XX, Slow Down"). Still other systems enhanced existing warning devices, incorporating flashing LEDs bordering chevron patterns to alert a driver to the presence of a curve.

Given the number of curve warning system deployments that have been made, the completion of several evaluations is not surprising. The findings of these evaluations have generally been consistent, with a significant reduction in excessive speed-related crashes in curves being found with California's deployments. Results in Oregon found that the system produced mean speed reductions of 2-3 mph depending on the direction of travel. Washington's initial evaluation of flashing LED chevron signs has found the number of vehicles exceeding the advisory speed limits for each curve fell. These findings provide an indication that curve warning systems can be effective at problem locations. However, the long-term effectiveness of such systems remains to be evaluated.

Table 3: Curve Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
Sidehill Viaduct Curve Warning System	California	I-5, postmile 29.97	Warn motorists of approaching curve and provide current speed	2000	Active	CMS sign, radar, system controller	Accidents related to excessive speed in curve significantly reduced
O'Brien Curve Warning System	California	I-5, postmile 32.22	Warn motorists of approaching curve and provide current speed	2000	Active	CMS sign, radar, system controller	Accidents related to excessive speed in curve significantly reduced
Salt Creek Curve Warning System	California	I-5, postmile 37.47	Warn motorists of approaching curve and provide current speed	2000	Active	CMS sign, radar, system controller	Accidents related to excessive speed in curve significantly reduced
La Moine Road Curve Warning System	California	I-5, postmile 49.19	Warn motorists of approaching curve and provide current speed	2000	Active	CMS sign, radar, system controller	Accidents related to excessive speed in curve significantly reduced
Sims Road Curve Warning System	California	I-5, postmile 57.87	Warn motorists of approaching curve and provide current speed	2000	Active	CMS sign, radar, system controller	Accidents related to excessive speed in curve significantly reduced
Ridgewood Grade Curve Warning System	California	U.S. 101, postmile 99.85	Provide curve warning to motorists	2010	Active	Radar unit, signal controller, CMS sign	N/A
Jitney Gulch Curve Warning System	California	U.S. 101, postmile 92	Provide curve warning to motorists	2010	Active	Radar unit, signal controller, CMS sign	N/A
Big Lagoon Curve Warning System	California	U.S. 101, postmile 111.21	Provide curve warning to motorists	2010	Active	Radar unit, signal controller, CMS sign	N/A
Myrtle Creek Advanced Curve Warning System	Oregon	I-5, milepost 107 - 109	Provide warning to motorists that they are driving too fast for curves	2004	Active	Radar units, system controller, overhead Dynamic Message Sign	Mean speeds reduced approximately 3 mph for southbound and 2 mph for northbound vehicles
Burnt River Canyon Advanced Curve Warning System	Oregon	I-84, milepost 340.5	Provide warning to motorists that they are driving too fast for curve	2012	Active	Radar units, system controller, overhead Dynamic Message Sign	N/A
U.S. 95 Advanced Curve Warning System	Oregon	U.S. 95, mp 51.5	Provide warning to motorists that they are driving too fast for curve	2011	Active	Radar units, system controller, overhead Dynamic Message Sign	N/A

Table 3 cont'd: Curve Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
Curve Speed Warning System	Washington	U.S. 101, MP 78.4; SR 7, MP 30.4	Provide warning to motorists that they are driving too fast for curve	2008	Inactive	Doppler radar units, system controller, Variable Message Signs, solar panels	Evaluation ongoing
King County Curve Warning System	Washington	Northeast Novelty Hill Road and Lake Holmes Road	Provide warning to motorists driving too fast to safely travel through downgrade curves	Aug. 2012	Active	Microwave vehicle detection sensors, system controller, static warning signs and flashing beacons, digital sign boards, centerline lights, solar panels	N/A
Beaverhead Rock Sequential Curve Warning System	Montana	MT 41, mileposts 13.7 and 15.1	Provide curve warning to high profile vehicles	2013	Active	Radar speed measurement, laser height measurement, system controller, static warning signs with flashing beacons	Evaluation ongoing
SR 17 Dynamic Curve Warning Systems	California	SR 171, postmile 9.5 - 10.0	Provide warning to motorists that they are driving too fast for curves	2006 and 2011	Active	Radar speed measurement, system controller, electronic warning signs	N/A
US 14A Dynamic Curve Warning Systems	Wyoming	US 14A, unknown milepost	Address curve-related crashes on a steep grade	2004	Active	Radar speed measurement, system controller, static metal signs with flashing beacons	N/A
Apple Bend / Spanish Fork Canyon Curve Speed Warning System	Utah	U.S. 6, milepost 192.2	Address crashes on a curve where speed was a factor	2006	Active	Radar speed measurement, system controller, EMS sign, solar power	N/A
Highway 6 Curve Speed Warning System	Utah	Hwy 6, milepost 141.5	Address crashes on a curve where speed was a factor	2006	Active	Radar speed measurement, system controller, EMS sign, solar power	N/A
SR 7 Sequential Dynamic Curve Speed Warning System	Washington	SR 7, milepost 31.7	Address crashes on a curve where speed was a factor	2012	Active	Radar speed measurement, system controller, standard chevron signs with flashing LEDs. Solar power, wireless communications	Mean speeds fell 1.4 mph Vehicles exceeding the posted advisory speed reduced
SR 203 Sequential Dynamic Curve Speed Warning System	Washington	SR 203, milepost 20.88	Address crashes on a curve where speed was a factor	2012	Active	Radar speed measurement, system controller, standard chevron signs with flashing LEDs. Solar power, wireless communications	Mean speeds fell 0.1 mph Portion of vehicles exceeding advisory speed by 10 mph+ fell
SR 9 Sequential Dynamic Curve Speed Warning System	Washington	SR 9, milepost 50.16	Address crashes on a curve where speed was a factor	2012	Active	Radar speed measurement, system controller, standard chevron signs with flashing LEDs. Solar power, wireless communications	Mean speeds fell 0.9 mph Portion of vehicles exceeding advisory speed by 10 mph+ fell

2.4. Traffic and Queue Warning Systems

Traffic and queue warning systems are somewhat of a niche category; these systems target 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 have been used at point locations, where crashes have historically occurred as the result of drivers unexpectedly encountering traffic or queues. Most of the systems identified during the work remain active, although some have been removed as highway upgrades have addressed the specific localized issue. Most recent deployments have relied on loop detectors to determine vehicle presence and speed (if necessary), although other technologies, such as general vehicle detectors or magnetometers, have also been used.

Regardless of the detection technology, 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. Regardless of the approach used to provide warning, the intent remains the same, to warn of slowed or stopped traffic. Perhaps because these systems are so basic in their components and function, no evaluations have been made for the systems identified by this work. As a result, it is not conclusively known whether reductions in crashes attributable to the systems have occurred.

Table 4: Traffic and Queue Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
Walker Road Traffic Warning System	California	U.S. 101, postmile R42.61	Warn motorists of slowed/stopped traffic ahead	mid 2000s	Active	Loop detector, signal controller, CMS sign	N/A
Confusion Hill Traffic Warning System	California	U.S. 101, postmile 99.3	Warn motorists of slowed/stopped traffic ahead	2009	Active	Loop detector, signal controller, CMS sign	N/A
Marysville Queue Warning System	California	SR 70, postmiles 13.5, 11.7 and 9.67	Warn motorists of slowed/stopped traffic ahead where view is obstructed	2007	Active	Loop detectors, controller, ramp metering software, CMS signs, wireless communications	N/A
Dundee Queue Detection System	Oregon	SR 99E, milepost 27.6 - 28.2	Reduce rear end crashes on a hilly section of roadway with reduced visibility of queued vehicles at a signal	1999	Inactive	Loop detectors, system controller, overhead warning signs with flashers	N/A
Eugene Queue Detection System	Oregon	Delta Highway, milepost 1.20 to Beltline interchange	Reduce rear end crashes on a hilly section of roadway with reduced visibility of queued vehicles at a signal	Fall 2011	Active	Traffic sensors, system controller, Dynamic Message Signs	N/A
Waldo Grade Queue Warning System	California	U.S. 101 on Waldo Grade	Address queuing issues related to slow moving buses	Unknown	Inactive	Traffic sensors, system controller, static metal signs with flashing beacons	N/A
I-580 Queue Warning System	California	I-580, postmile 45	Address queuing issues related to an interchange	Unknown	Inactive	Magnetometers, system controller, static metal signs with flashing beacons	N/A
U.S. 101 Queue Warning System	California	U.S. 101, postmile 457	Address queuing issues related to an interchange	Unknown	Active	Loop detectors, system controller, EMS sign	N/A

2.5. 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. This is likely the result of the nature of VSL systems, which are largely deployed in urban areas where agency personnel have a strong interest in monitoring the continually changing conditions and verifying the speed limits being set and activated by the system. Still, during the course of the work, three VSL systems were identified that are fully automated. These deployments are presented in Table 5. In two cases, these systems cover longer lengths of corridor and address prevailing traffic and weather conditions, while one system is more location-specific, addressing speed issues in the vicinity of an intersection with seasonally high traffic volumes.

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 this 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 via VMS signs in one case. The weather-based VSL identified during this 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.

To date, general evaluation activities have been completed that have shown encouraging results. The weather-based VSL system has produced reductions in crashes and vehicle speeds during inclement conditions. The VSL system installed to address intersection crashes has produced lower mean and 85th percentile vehicle speeds at times when the system has been activated. As these results suggest, automated VSL systems can produce benefits to safety and operations. As the other VSL systems that have been deployed in the western U.S. remain active and agencies build up experience with their use, some of these systems may transition to more automated operation similar to the examples presented here.

Table 5: Variable Speed Limit Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
Urban Advanced Traffic Management System	Washington	I-5, mp 157.23-164.46; I-90, mp 2.81-11.71; SR 520	Reduce accident rates by providing advanced notice of lane closures or merging ahead	Fall 2009	Active	Loop detectors, sidefire radar, control computers, fiber optic/LED signs and masts over lanes at ½ mile intervals, VMS	Evaluation ongoing
Snoqualmie and Stevens Pass Winter Weather Variable Speed Limit Systems	Washington	I-90, milepost 33-71; U.S.-2, milepost 57.49 – 105.31	Reduce accident rates during winter weather	1997 (I-90); 2011 (US-2)	Active	RWIS, central control computer, Variable Speed Limit signs	Snoqualmie Pass system has been effective in reducing speeds and crashes
Staley's Junction Variable Speed System	Oregon	Intersection of U.S. 26 and OR 47	Reduce intersection crashes	2010	Active	Traffic sensors, central controller, Variable Speed Limit signs, flashing warning signs	85^{th} percentile and average vehicle speeds on U.S. 26 lower when system is operating

2.6. 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. Regardless of the action taken, the goal of these systems is to prevent crashes from occurring. All of the systems documented in this work were deployed in the 2000s and remain active to date. Table 6 provides further details of these systems.

The technologies used in developing these systems can range from basic anemometers to complete RWIS stations. Regardless, the primary data being measured are wind speeds and directions, which are 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.

Perhaps as a result of their basic purposes and components, only a limited number of wind warning systems have had their effectiveness evaluated. Those systems that were evaluated focused on driver recognition and trust of the system, finding 80 to 84 percent of respondents believed the system provided information that was accurate. Further, a fair portion of those surveyed had seen and observed the signs, ranging from 60 to 75 percent of respondents.

Table 6: Wind Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
South Coast Wind Warning System	Oregon	U.S. 101, mp 300 - 330	Warn motorists of high wind speeds	2004	Active	Anemometer, controller, radio communications, static warning signs with flashing beacons	84 percent of drivers believed system provided accurate information and warning 75 percent of drivers had seen/observed signs
Yaquina Bay Wind Warning System	Oregon	U.S. 101, mp 141.27 – 142.08	Warn motorists of high wind speeds on bridge	2004	Active	Anemometer, controller, radio communications, static warning signs with flashing beacons	80 percent of drivers believed the system provided accurate information and warning 60 percent of drivers had seen/observed the signs
Dual Use Safety Technology Warning System	Arizona	I-10, Texas Canyon Pass	Warn motorists of low visibility and/or high wind speeds	2012	Active	Anemometers, wind speed indicators, visibility sensors, cameras, controller, DMS signs equipped with flashing beacons and HAR	N/A
Vantage Bridge Wind Warning System	Washington	I-90, mp 137.19	Provide trucks with high wind warning prior to entering bridge	2009	Active	Weather station for wind detection, controller, static warning signs equipped with flashing beacons	N/A
I-10 Wind Warning System	New Mexico	I-10, mp 11-12	Provide drivers with warning of reduced visibility due to dust	2011	Active	RWIS, controller, HAR, static warning signs equipped with flashing beacons	N/A
Conway Summit Automated Wind Warning System	California	U.S. 395, pm 59	Provide drivers with warning of high winds	2011	Active	Wind speed and direction sensors, controller, static warning signs equipped with flashing beacons, solar power	N/A
I-580 Wind Warning System	Nevada	I-580, mp 44 - 56	Provide drivers of high profile vehicles with high wind warning	2002	Active	RWIS stations, system controller, static warning signs equipped with flashing beacons, DMS	N/A

2.7. 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. As a result, runaway truck ramp warning systems have been deployed to provide advanced warning that a ramp is in use as well as to notify maintenance forces that the arresting bed may need to be repaired.

All of the ramp warning systems documented by this work were deployed in the 2000s and remain active. The systems are generally straightforward in detecting vehicle presence, using loop or radar detectors or general sensors, as outlined in Table 7. Once a vehicle is detected, the system controller triggers a warning action, which can range 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. In one case, the camera also provided agency staff with a visual verification that a truck had entered the ramp as opposed to another mechanism triggering the system. Specifically, one agency had experienced issues with passenger vehicles using the ramp area to stop for picnics. This use of the ramp area could have severe consequences in the event that a runaway truck approached without warning that the ramp was occupied in such a manner.

Table 7: Runaway Truck Ramp Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
Arizona Runaway Truck Ramp Warning Systems	Arizona	Two sites along SR 68 near Kingman	Provide warning ramp is occupied	2008	Active	Sensors to detect truck presence, CCTV, system controller, DMS signs	N/A
U.S. 16 Runaway Truck Ramp Warning System	Wyoming	U.S. 16 eastbound, west of Buffalo	Provide warning ramp is occupied	2004	Active	Radar to detect presence, system controller, static metal signs with flashing beacons	N/A
I-5 Truck Escape Ramp Warning System	California	I-5, postmiles 8.23 and 8.24	Provide warning ramp is occupied	2005	Active	Inductive loops to detect presence, system controller, EMS signs, CCTV	N/A

2.8. 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 provide warning for a short segment of low lying roadway or at bridge locations. The systems documented during this work were deployed in the 2000s and three of four identified remain active to date. Table 8 presents further details on these systems.

The mechanisms used to detect water presence or level have been straightforward, relying on ultrasonic, radar or float sensors. When water is detected as present or having reached a certain threshold, the system controller activates the warning mechanisms, which in all cases were flashing beacons on static metal warning signs. In one case, a system that is now inactive did not provide driver warning but instead autodialed agency maintenance staff who then went into the field and deployed warning signage. None of the flood warning systems identified have been evaluated for their effectiveness to date.

Table 8: Flood Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
Cushman Flood Warning System	Oregon	SR 126, mp 2.9 – 3.1	Warn of water/flooding at a low point on road	2006	Active	Float sensors, system controller, static warning signs with flashing beacons	N/A
Seaside Flood Warning System	Oregon	U.S. 101, mp 22.66 – 23.54	Warn of water/flooding at a low point on road	2006	Active	Ultrasonic level sensors, system controller, static warning signs with flashing beacons	N/A
Tillamook Flood Warning System	Oregon	Willson River bridge, in Tillamook	Provide maintenance manager of warning for potential flooding	2000	Inactive	Ultrasonic level sensors, autodialer	N/A
Sonoma Creek Flood Warning System	California	SR 121, pm 7.3	Warn motorists of creek flooding at bridge	2003	Active	Radar level sensors, system controller, static warning signs with flashing beacons	N/A

2.9. 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. The systems documented in this work have been deployed in the field since the 1990s and the majority remains active to date. Details on these systems are presented in Table 9.

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. To date, no visibility warning system has been evaluated to determine its effectiveness.

Table 9: Visibility Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
I-15 Dust Warning System	Montana	I-15, mp 389	Provide drivers with warning of reduced visibility	2013	Active	Visibility sensors, system controller, flashing beacons on static metal signs	N/A
District 10 Visibility Warning System	California	I-5, pm 15.9, 17.04, 18.81, 20.22 and 21.96; SR 120, pm 0.60, 2.76, 4.79 and 6.07	Provide warning of low visibility and presence of highway congestion	Nov. 1996	Active	Meteorological stations, traffic speed detectors, system controllers and CMS	N/A
I-215 Low Visibility Warning System	Utah	I-215, mileposts 10 - 15	Provide warning of low visibility due to inversions	Winter 1999	Inactive	Forward-scatter visibility sensors, vehicle detection sensors, system controller, DMS signs	N/A
District 6 Fog Detection and Warning System	California	SR 99, pm 10.5 - 52.24	Provide warning of low visibility and presence of highway congestion	2009	Active	Weather stations, visibility sensors, CCTV, microwave vehicle speed detectors, system controllers and CMS	N/A
SR 18 Visibility Warning System	California	SR 138 at intersection with SR 2	Provide warning during low visibility of signalized intersection ahead	2013	Active	Visibility sensor, system controller and DMS signs	N/A
SR 138 Visibility Warning System	California	SR 18 at intersection with Lake Gregory Drive	Provide warning during low visibility of signalized intersection ahead	2010	Active	Visibility sensor, system controller and DMS signs	N/A

2.10. General Warning Systems

In addition to the systems already discussed in prior sections, other safety warning systems were identified during the course of this work that do not fit into one of the other established categories. Instead, these systems have been grouped together in this section as they provide warnings for specific conditions that do not necessarily occur with any frequency in other locations. The following summaries cover these systems at a high level, with further details presented in Table 10.

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. These systems use inductive loops or radar to detect vehicle length. When the system controller determines an overlength vehicle is present, flashing beacons on static metal warning signs are activated to provide warning to the overlength vehicle driver to not continue on the route. To date, the systems identified have not had their effectiveness evaluated.

A unique system has been deployed in the Seattle area to address the potential for earthquakes to damage a viaduct structure. An earthquake warning system is used 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. The system uses seismic sensors, a controller and closure gates to prevent vehicles from entering the structure after an event has been detected. The effectiveness of this system has not been evaluated.

Automated travel time systems are in use to provide drivers with an indication of the times required to reach different points on the road network. The systems identified in this work were urban-based and used different technologies and approaches to establish travel times, including license plate readers, loop detectors, 3rd party data, toll tag readers and microwave vehicle detection systems. Data was processed by a central computer, with travel time information provided to drivers via CMS, DMS and VMS signs. To date, the systems identified have not had their effectiveness established. One note to bear in mind when reviewing these systems is that they were considered to be entirely automated by their respective agencies. Other travel time systems present in areas such as Los Angeles and the San Francisco/Oakland area have also been deployed, but these systems were not viewed as being automated by their operators.

Overheight detection systems are used to provide warning that a vehicle’s height will not clear an upcoming structure, typically a bridge. These systems use infrared and other sensors to detect vehicles that exceed a certain height. When an overheight vehicle is detected, the system controller activates flashing beacons on static warning signs or an EMS sign to provide warning that a vehicle should take a detour route. The effectiveness of these systems has not been evaluated.

Downhill speed systems provide warning to heavy vehicles of an upcoming downgrade. In some cases, a vehicle-specific message and advised speed are provided. These systems use a variety of technologies to detect heavy vehicles and provide feedback, including transponder readers, inductive loops or Piezo sensors. The system controller uses inputs from these sensors to activate the system and, in some cases, provide a vehicle-specific speed limit. This information is provided to divers via CMS or VMS signs in the systems documented by this work. One evaluation of a downhill speed system found that truck speeds were 7.6 mph lower when the system was operating versus when it was not operating.

Table 10: General Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
U.S. 395 Over Length Detection System	Oregon	U.S. 395, mp 50 - 60	Provide warning of over length vehicle in corridor	2012	Active	Wavetronix length detection unit, controller, static metal signs with flashing beacons	N/A
McKenzie Over Length Detection System	Oregon	SR 242; mp 61 – 84	Provide warning of over length vehicle in corridor	2004	Active	Inductive loops to detect vehicle occupancy and speed, central controller, static warning signs with flashing beacons	N/A
Alaskan Way Viaduct Earthquake Warning System	Seattle, WA	Alaskan Way Viaduct	Close viaduct when seismic activity detected	2011	Active	Seismic sensors, system controllers, road closure gates	N/A
King County Travel Time System	Washington	Avondale Road Northeast, Redmond WA	Provide travel time information	Spring, 2013	Active	License plate readers, Wavetronix detection sensors, central computer, changeable message signs	N/A
Phoenix Travel Time System	Arizona	Metropolitan Phoenix area	Provide travel time information	2008	Active	Loop detectors and 3rd party data to establish travel speeds, central processing computer, dynamic message signs	N/A
Denver Area Travel Time System	Colorado	I-25 and I-70	Provide travel time information	2005	Active	Traffic detectors, toll tag readers, central processing computer, variable message signs	N/A
Harrisburg Bridge Over-Height Vehicle Warning System	Oregon	State Route 99E, Harrisburg, OR	Warn approaching vehicle it is overheight	Dec. 2001	Active	Bi-directional infrared transmitter and receivers, system controller, flashing beacons on static warning signs	N/A
Downhill Speed Information System	Oregon	I-84, mp 227.4	Provide trucks with warnings for steep downgrade	Dec. 2002	Active	Transponder reader, system controller, access to upstream weigh in motion data, CMS sign	N/A
I-70 Dynamic Downhill Truck Speed Warning System	Colorado	I-70, at Eisenhower tunnel	Provide trucks with a recommended advisory speed for downgrade	1998	Active	Inductive loops, Piezo sensors, system controller, VMS sign	Truck drivers surveyed had positive views of the system Truck speeds were 7.6 mph lower when system operating
I-25 Overheight Vehicle Detection System	Wyoming	I-25, mp 184.0 – 184.85	Provide trucks with an overheight warning before reaching I-80 from I-25	2009	Active	Overhight detectors, system controller, EMS sign	N/A

Table 10 cont'd: General Warning Systems

System Name	State	Location	Purpose	Deployed	Status	Components	Evaluation Results
Little Cottonwood Canyon Avalanche Detection System	Utah	Hwy 210, Little Cottonwood Canyon	Provide DOT personnel with notification of potential avalanche	2007	Active	Infrasonic sensor arrays, central computer for data processing	N/A
Highway 189 Avalanche Detection System	Wyoming	Hwy 189 on Teton Pass	Provide DOT personnel with notification of potential avalanche	2003-2004	Active	Infrasonic sensor arrays, central computer for data processing	N/A
Highway 99 Tunnel Closure System	Seattle, WA	replacement of Hwy 99	Close tunnel when seismic activity or fire detected	2013	Active	Seismic and fire sensors, central control computer, road closure gates, DMS	N/A
Tunnel Fire Detection and Closure Systems	Seattle, WA	I-5, mp 166; I-90, mp 4; I-90, mp 6	Close tunnels when fires are detected	1988 and 1990s	Active	Fire detection sensors, system controller, electronic signs, red signals	N/A

Avalanche detection systems are used to determine when avalanches have potentially occurred. To date, these systems are only used for detection and are not used to provide a warning to drivers or close a segment of roadway. The systems use infrasonic sensor arrays to determine the occurrence and approximate location of an avalanche. Array data is processed by a central computer and when an event has occurred, notification is sent to maintenance personnel via cellular phone calls and pages. Maintenance personnel then visit the field and perform any necessary road closure and maintenance functions. These systems have not been extensively evaluated to date.

The final type of general warning system identified was tunnel closure systems. These systems close tunnels in the event of an earthquake or fire to prevent drivers from becoming trapped. The systems use seismic and fire sensors, with the system controllers determining if a hazard is present. In the event of a fire or earthquake, the controller triggers closure gates, red signals and messages on DMS signs. These systems are relatively new and have not been evaluated for effectiveness.

3. SYNTHESIS OF SYSTEMS

This chapter presents the findings of interviews with various staff in each of the states of interest regarding the automated safety warning systems they have managed and deployed both in the past and at present. The systems presented in this chapter are grouped by function and purpose rather than by state/location. However, locational information is presented for all systems for reader reference. For readers interested in obtaining additional information, the system's general location (route and milepost or intersection) may be useful when contacting a specific agency for follow-up discussion.

3.1. Ice and Weather Warning Systems

Ice and weather warning systems provide warning to drivers of local or upcoming conditions resulting from weather. For example, ice warning systems may provide drivers with a localized warning of ice on the pavement ahead in critical locations such as curves. Weather warning systems may provide advanced warning of hazardous conditions resulting from a storm miles ahead, providing an opportunity to halt travel or consider an alternative route. The research team identified a total of 11 such systems that are presently deployed in the survey states or have been deployed in the past.

3.1.1. Fredonyer Summit Icy Curve Warning System (California)

The Fredonyer Summit Icy Curve Warning System (ICWS) in Lassen County, California, is designed to detect icy conditions and provide a warning to motorists; it has been active since the fall of 2008. Installed by Caltrans District 2, it is located on Lassen Highway 36 between postmiles 10.45 and 11.89. The roadway has mixed posted speed limits (45-55 mph), two lanes, with climbing/passing lanes along most of its length, and is undivided. The system is along a section of roadway that frequently experiences icy conditions due to snow melt and shading.

The system uses embedded pavement sensors to detect when conditions are present on the pavement surface that can result in ice formation. The system is comprised of these pavement surface sensors, an RWIS and Outpost, Extinguishable Message Signs (EMS), amber flashers (mounted on the EMS), CCTV, communications systems, and battery back-up equipment. When such conditions are detected, the EMS and amber flashers located at each end of the segment are activated, displaying a message of “ICY CURVES AHEAD” with the flashers alternately flashing.

The system appears to have been effective at slowing drivers when icy conditions are present. This has been observed both anecdotally, as well as through a formal evaluation. Statistical analysis of speed data suggest that the system is working as intended and that vehicle speeds are significantly lower. Changes in mean vehicle speeds during clear, cold and not dry conditions exceeding 3 mph were observed both during the day and at night at the sites. However, only a limited number of mean speed differences were found to be greater than 5 mph. The effect of the system on crash frequencies was also evaluated, with results finding that the deployment of the ICWS reduced the number of annual crashes by 18%. However, the analysis relied on a short study period of data and a long-term evaluation is still needed.

Based on the experiences with this system, it is possible that it would be deployed again elsewhere if the need arises, provided that long-term evaluations confirm a safety benefit through reduced crashes. The primary improvement that would be made is the use of more sensors in areas where the pavement is likely to be the first to freeze and last to thaw.

Purpose: Detect icy conditions and provide warning to motorists.

Status: Active

Deployed: Fall, 2008

Location: Lassen Highway 36, pm 10.45 and 11.89.

Components: Pavement sensors, RWIS, system controller, EMS, amber flashers, CCTV, communications, battery back-up.

System Contact:
Ian Turnbull, P.E.
Chief, Office of ITS Engineering and Support
California Department of Transportation
Telephone: (530) 225-3320
Email: ian_turnbull@dot.ca.gov

Evaluation: http://www.westernstates.org/projects/coats/Documents/Fredonyer%20Eval-8-1-2011.pdf

3.1.2. Fredonyer East Icy Curve Warning System (California)

The Fredonyer East Icy Curve Warning System in Lassen County, California, is designed to detect icy conditions and provide a warning to motorists; it has been active since the fall of 2008. Installed by Caltrans District 2, it is located on Lassen Highway 36 between postmiles 13.32 and 14.35. The roadway has mixed posted speed limits (45-55 mph), two lanes, with climbing/passing lanes along most of its length, and is undivided. The system is along a section of roadway that frequently experiences icy conditions due to snow melt and shading.

The system uses embedded pavement sensors to detect when conditions are present on the pavement surface that can result in ice formation. The system is comprised of these pavement surface sensors, an RWIS and Outpost, Extinguishable Message Signs (EMS), amber flashers (mounted on the EMS), CCTV, communications systems, and battery back-up equipment. When such conditions are detected, the EMS and amber flashers located at each end of the segment are activated, displaying a message of "ICY CURVES AHEAD" with the flashers alternately flashing.

The system appears to have been effective at slowing drivers when icy conditions are present. This has been observed both anecdotally, as well as through a formal evaluation. Statistical analysis of speed data suggest that the system is working as intended and that vehicle speeds are significantly lower. Changes in mean vehicle speeds during clear, cold and not dry conditions exceeding 3 mph were observed both during the day and at night at the sites. However, only a limited number of mean speed differences were found to be greater than 5 mph. The effect of the system on crash frequencies was also evaluated, with results finding that the deployment of the ICWS reduced the number of annual crashes by 18%. However, the analysis relied on a short study period of data and a long-term evaluation is still needed.

Based on the experiences with this system, it is possible that it would be deployed again elsewhere if the need arises, provided that long-term evaluations confirm a safety benefit through reduced crashes. The primary improvement that would be made is the use of more sensors in areas where the pavement is likely to be the first to freeze and last to thaw.

Purpose: Detect icy conditions and provide warning to motorists.

Status: Active

Deployed: Fall, 2008

Location: Lassen Highway 36, pm 13.32 and 14.35.

Components: Pavement sensors, RWIS, system controller, EMS, amber flashers, CCTV, communications, battery back-up.

System Contact:
Ian Turnbull, P.E.
Chief, Office of ITS Engineering and Support
California Department of Transportation
Telephone: (530) 225-3320
Email: ian_turnbull@dot.ca.gov

Evaluation: http://www.westernstates.org/projects/coats/Documents/Fredonyer%20Eval-8-1-2011.pdf

3.1.3. Spring Garden Icy Curve Warning System (California)

The Spring Garden Icy Curve Warning System in Plumas County, California, is designed to detect icy conditions and provide a warning to motorists; it has been active since the fall of 2008. Installed by Caltrans District 2, it is located on Plumas Highway 70 between postmiles 50.07 and 51.64. The roadway is high speed (>55 mph), two lanes, with climbing/passing lanes along most of its length, and undivided. The system is along a section of roadway that frequently experiences icy conditions due to snow melt and shading.

The system uses embedded pavement sensors to detect when conditions are present on the pavement surface that can result in ice formation. The system is comprised of these pavement surface sensors, an RWIS, Changeable Message Signs (CMS), CCTV, communications systems, and battery back-up equipment. When such conditions are detected, the CMS located at each end of the segment are activated and flash a message of "CAUTION ICY ROAD".

The system appears to have been effective at slowing drivers down when icy conditions are present based on observations. It is too early to tell the impact the system has had on reducing crashes.

Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere if the need arises, provided that future, long-term evaluations confirm a safety benefit through reduced crashes. The primary improvement that would be made to the overall system is the use of more pavement sensors in areas where the pavement is likely to be the first to freeze and last to thaw.

Purpose: Detect icy conditions and provide warning to motorists.

Status: Active

Deployed: December, 2009

Location: Plumas Highway 70, pm 50.07 and 51.64.

Components: Pavement sensors, RWIS, system controller, Model 510 CMSs, CCTV, battery back-up.

System Contact:
Ian Turnbull, P.E.
Chief, Office of ITS Engineering and Support
California Department of Transportation
Telephone: (530) 225-3320
Email: ian_turnbull@dot.ca.gov

3.1.4. Butte Creek Ice Warning System (Oregon)

The Butte Creek ice warning system in Klamath County, Oregon, is designed to detect icy conditions and provide a warning to motorists. The system was first activated in November, 2005. It is located on Oregon Highway 140 between mileposts 21.7 and 41.7. The roadway is high speed (generally 55 mph), two lanes, with climbing/passing lanes along most of its length, and undivided. The system is deployed along a mountainous section of roadway that frequently experiences icy conditions due to weather and geography.

The system uses a suite of environmental and pavement sensors to detect weather and pavement conditions that could result in icy pavement. When the weather and pavement data processed by the system controller indicate icy conditions are present, static warning signs with flashers are turned on at either end of the corridor.

A system evaluation conducted during the winter of 2007 – 2008 found mixed results. The system did appear to produce reductions in vehicle speeds when the beacons were flashing. Additionally, surveys of drivers along the corridor found that they were aware of the signs and beacons and had confidence that the warning was accurate. No decreases in crashes had been observed at the time of the study, although it was still too early on in the deployment to tell the impact the system may have had.

Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere if the need arises. In future deployments, the technology used to sense/establish ice presence would be changed, likely incorporating non-intrusive sensors that use infrared and spectroscopic sensing to determine pavement surface state. A key benefit from the use of such sensors is expected to be a reduction in maintenance needs (fewer sensors resulting in fewer items to fix or maintain).

Purpose: Provide warning to motorists of icy road conditions on a mountainous roadway.

Status: Active

Deployed: November 2005

Location: OR 140, MP 21.7 - 41.7.

Components: Wind direction/speed, moisture, temperature, humidity/dew point, and pavement condition sensors, system controller, static warning signs with flashers.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

Evaluation:
https://wiki.cecs.pdx.edu/pub/ItsWeb/OR140IceWarningSystemEvaluation/140_report_compiled.pdf

3.1.5. King County Road Weather Warning System (Washington)

The road weather warning system in King County, Washington, is designed to detect icy and slick pavement conditions and provide a warning to motorists. The system was activated during the spring of 2013. It is located along the South 277th Street and South 272nd Street corridor (roadway changes designation around 5th Avenue South) through Kent and Auburn, Washington. The roadway is high speed (generally 45+ mph), four lanes, and undivided. The route is a steep and curving arterial that is shadowed by a good deal of vegetation. This results in the potential for ice-related crashes to occur. The purpose of the system is to address these conditions by providing motorists with warning, as well as provide maintenance forces with an automated warning that indicates when they should perform operations along the route. Finally, the system automates a process that had required maintenance forces to open a static flip warning sign in the field.

The system uses one pavement temperature sensor, one roadside thermometer and one humidity sensor to detect current conditions. This information is sent back to a central computer for processing at the TMC. When conditions are indicative of ice forming or the potential for slick roads, a warning message of "Watch for Ice" is posted to extinguishable message signs along the corridor.

As the system has not yet been activated, no evaluations of its performance have been made. However, during development of the system, it was determined that the sign controller did not allow for a manual override of the posted ice warning message. Such an override would be useful in allowing alternative warning messages to be posted, such as notification of a crash ahead. The controller manufacturer is developing software to allow this override, but it is something to be aware of when developing a similar system.

Purpose: Provide warning to motorists of icy road conditions on a shaded roadway segment.

Status: Presently being installed

Deployed: 2013

Location: South 277th Street and South 272nd Street corridor through Kent and Auburn, Washington.

Components: One pavement temperature sensor, one roadside thermometer, one humidity sensor, central processing computer, extinguishable message signs.

System Contact:
Aileen McManus
ITS Project Manager
King County (Washington) Roads Division
Telephone: (206) 263-6135
Email: aileen.mcmanus@kingcounty.gov

3.1.6. Road Weather Information System Warning System (Arizona)

The Arizona Department of Transportation has developed a component to their RWIS system that sends an email notice to alert maintenance personnel that pavement sensors have detected deteriorated conditions (snow, ice) that require winter maintenance treatments. This ensures timelier maintenance operations are performed, enhancing motorist safety. The RWIS sites that are included in this notification are on I-10, I-40, SR 93, SR 771, SR 260, SR 377, SR 277, SR 264 and SR 87. These sites are comprised of a variety of divided and undivided cross sections and speed limits.

The system consists of the RWIS station components at each site, as well as a central processing computer that evaluates the data and sends the email alerts. To date the system has worked well, although no formal evaluations of its performance or impacts have been made. Additional RWIS sites will be added to the system as they are deployed.

Purpose: Provide automated notice to maintenance staff that pavement conditions have deteriorated and require winter maintenance, enhancing motorist safety.

Status: Active

Deployed: 2006

Location: I-10, I-40 (17 sites on interstates), SR 93 (Kaiser Bridge), SR 260/SR 377/SR 277 Junction, SR 264 (Window Rock), SR 87 (Clints Well).

Components: RWIS stations/components, central control computer.

System Contact:
Reza Karimvand
Assistant State Engineer
Arizona Department of Transportation
Telephone: (602) 712-8328
Email: RKarimvand@azdot.gov

3.1.7. Idaho Storm Warning System (Idaho)

The Idaho Transportation Department developed a storm warning system to provide motorists with advanced notice of blowing/heavy snow or dust along I-84 in southeast Idaho. These types of conditions had resulted in a number of crashes over time, prompting the deployment of the warning system in 1993. The system, which covers a 100 mile stretch of I-84 between milepost 222 (Idaho) and milepost 41 (Utah), had variable message signs located at either end of the corridor to provide warning of road conditions ahead. The original system was deactivated in 2003, and has since been replaced by one with updated components and technologies.

The system used three visibility forward scatter optical sensors, RWIS and traffic counters to identify hazardous conditions, particularly reduced visibility. The data from these sensors was processed by the system controller to determine when visibility thresholds had fallen below a pre-established point. When the system determined visibility was low, four variable message signs were activated to provide motorists with a warning of low visibility or other hazardous road conditions. The signs were located at the junction of I-84 and I-86 in Idaho, and the junction of I-15 and I-84 in Utah.

An evaluation of the system between 1993 and 2000 found that speed variance under high wind conditions fell by 23 percent, from 58.4 mph to 42.3 mph. When high winds and precipitation were detected, average speeds fell by 12 percent, from 47.0 mph to 41.2 mph. Average speeds under snow covered pavement and high wind conditions fell from 54.7 mph to 35.4 mph when warnings were posted.

As the results of the different speed analyses show, the system was effective in making motorists aware of hazardous conditions and producing lower vehicle speeds. The original system did have issues, however. This included hardware and software compatibility problems, and communications and power reliability. Uninterrupted power supply was a critical need identified for this type of system after it was initially developed. However, these issues have not prevented a newer version of the system using updated components from being deployed in place of the original one.

Purpose: Address poor visibility crashes on I-84 in southeast Idaho that were the result of blowing/heavy snow and blowing dust.

Status: Original system deactivated.

Deployed: 1993 - 2003

Location: I-84 from mp 222 (Idaho) to mp 41 (Utah).

Components: Visibility, weather and traffic sensors, system controller, variable message signs.

System Contact:
Robert Koeberlein
Mobility Services Engineer
Idaho Transportation Department
Telephone: (208) 334-8487
Email: Robert.koeberlein@itd.idaho.gov

Evaluation: http://ntl.bts.gov/lib/11000/11100/11191/cc01.pdf

3.1.8. Carlin Tunnels Ice Warning System (Nevada)

The Nevada Department of Transportation has maintained an ice warning system for travelers at the Carlin tunnels on I-80 since 1985, and it remains active. The system is located at milepost 260, along a high speed (70 mph) four lane, divided roadway segment that passes through a tunnel. The intent of the system is to warn drivers of the presence of ice within the tunnel. The system was rebuilt and upgraded during 2013.

The system uses pavement surface sensors and noninvasive infrared grip sensors to detect actual ice (not the potential for it). The information from these sensors is used by the system controller to activate flashing beacons on static metal warning signs.

No formal evaluations of the system have been made to date, but observations by staff have indicated that it is moderately effective in detecting ice and providing warning. The original pavement surface sensors used with the system were not placed far enough in the tunnels, so not all ice conditions were detected. The recent improvements (2013) made to the system have used infrared detection to make grip measurements, which is expected to improve the accuracy of the system in determining ice conditions. However, a similar system would be used again if the need arose. The one improvement that would be incorporated into the system would be a more open platform on the system controller.

Purpose: Provide warning to motorists of ice presence in tunnels.

Status: Active

Deployed: 1985, upgraded 2013

Location: I-80, Carlin Tunnels, MP 260.

Components: In-pavement ice detection pavement surface sensors, infrared grip sensors, system controller, static warning signs with flashing beacons.

System Contact:
Jon Dickinson
ITS Project Manager
Nevada Department of Transportation
Telephone: (775) 888-7560
Email: jdickinson@dot.state.nv.us

3.1.9. Nugget Canyon Ice Warning System (Wyoming)

The Wyoming DOT deployed an ice warning system for a curved bridge site in Nugget Canyon on U.S. 30 in the early 2000's. The location had experienced a number of crashes related to ice on the bridge over time, and the system was deployed to address the problem. As indicated, the site is a curved bridge on U.S. 30 at approximately milepost 34. The road is two undivided lanes with a speed limit of 65 mph. The system remains active to date.

The system uses an RWIS station to determine if there is a potential for ice formation on the roadway based on air temperature (note that pavement conditions on the bridge are not measured). If ice formation is possible, the system controller activates the flashing beacons on static metal warning signs located at either end of the bridge.

No formal evaluation of the system has been performed to date. However, observations by WYDOT staff indicate that it has helped reduce crashes over time and the public seems to rely on it for the general conditions on the bridge itself. Based on its performance, the system would be used again elsewhere if needed. However, the system would incorporate pavement surface sensors on the pavement of the bridge to detect surface conditions in order to provide additional data for establishing the presence of ice. Aside from this improvement, no other changes are viewed as needed.

Purpose: Provide ice warning for curved bridge.

Status: Active

Deployed: Early 2000's

Location: U.S. 30, MP 34.

Components: RWIS, system controller, static metal signs with flashing beacons, solar power.

System Contact:
Aaron Huffsmith
ITS Research Engineer
Wyoming Department of Transportation
Telephone: (307) 777-4232
Email: aaron.huffsmith@dot.state.wy.us

3.1.10. Piney Creek Ice Warning System (Wyoming)

The Wyoming DOT deployed an ice warning system for a bridge site at Piney Creek on I-90 in 2006. The location had experienced a high number of ice-related bridge crashes, which the system was deployed to address. The site is located on I-90 at the bridges over Piney Creek. The road is four lanes with a speed limit of 75 mph and divided. The system remains active to date.

The system uses pavement surface sensors on the bridge deck to detect pavement conditions and air temperature sensors to collect atmospheric conditions. Based on the data from these sensors, if ice formation is possible based on condition thresholds, the system controller activates the flashing beacons on static metal warning signs located at either end of the bridges crossing the creek.

No formal evaluation of the system has been performed to date, but in general the system seems to have addressed crashes. Based on its performance, the system would be used again elsewhere if needed. The system itself is relatively affordable, making it applicable in other locations. Based on its straightforward nature and performance over time, no additional improvements are viewed as necessary.

Purpose: Provide ice warning for interstate bridges.

Status: Active

Deployed: 2006

Location: I-90 crossing of Piney Creek.

Components: Pavement condition sensors, air temperature sensors, system controller, static metal signs with flashing beacons.

System Contact:
Kevin Cox
Systems Engineer
Wyoming Department of Transportation
Telephone: (307) 777-4620
Email: kevin.cox@dot.state.wy.us

3.1.11. Fish Creek Icy Bridge Detection and Warning System (Utah)

The Utah DOT deployed an ice detection and warning system for a bridge site at Fish Creek on I-70 in 2013. The location had experienced a high number of crashes as attributed to "ice on bridge deck", including fatal crashes. The site is at milepost 11.5, along a high speed (70 mph) divided, four lane section of interstate.

The system uses an RWIS station to monitor for snow and ice presence on the west end of the bridge deck. When the system controller determines snow or ice are present (note that a certain threshold is not employed), a warning stating "Icy Bridge Ahead" is posted to two CMS signs on the roadside. The system is solar powered owing to the remote location of the site, which has presented challenges since deployment.

Given the recent deployment date, the system has not been evaluated. However, there have been issues to date with the solar power aspect of the system. Specifically, while every effort was made to correctly design the solar array to meet the characteristics of the site, the array installed with the system was found to be undersized. Efforts are ongoing to expand the solar array to provide more capacity than needed. In addition, while a firm completed an analysis of whether there would be good wireless signal strength in the area to allow communication between the system controller and CMS signs, the repeaters have not worked effectively to date. Aside from these issues, if the system is observed to work well, it will be considered for use at other sites in the area.

Purpose: Provide ice warning for bridge.

Status: Active

Deployed: 2013

Location: I-70 crossing of Fish Creek, mp 11.5.

Components: RWIS station, system controller, CMS signs, wireless communications, solar power.

System Contact:
Troy Torgersen
Project Manager
Utah Department of Transportation
Telephone: (435) 896-1303
Email: ttorgersen@utah.gov

3.2. Animal Warning Systems

Animal warning systems are perhaps the most experimental in nature of the systems reviewed in this document. The intent of such systems has always been basic: to provide drivers with warning of animals in vicinity of the roadside. Over time, as the following sections will illustrate, a number of different approaches to detecting animal presence at the roadside and providing drivers with a corresponding warning have been tried in different states. In general, these approaches have had limited success, and most of the systems highlighted in the following sections have been deactivated and removed.

3.2.1. PATH/Fort Jones Animal Warning System (California)

The PATH/Fort Jones animal warning system on SR 3 was deployed to evaluate a detection and warning system for black tailed deer within a high animal-vehicle crash corridor. The system was initially deployed in September, 2009 and removed in the summer of 2013 following the completion of the evaluation. The system was deployed between postmiles 36.50 and 37.30, a high speed (55 mph), two lane segment of undivided roadway. The deer in the area were attracted to this location based on the crops planted by farmers.

The system used radar between posts on the roadway segment. When the radar beam was broken, the system classified it as indicating the presence of an animal. The system controller activated four LED signs along the roadside (one at either end of the segment and one located 1/3 of a mile into the segment from both directions), which displayed a deer warning image with flashing amber symbols on either side. This image remained active on the sign for approximately 3 minutes.

A formal evaluation of the system was published in 2012. The evaluation found that mean traffic speeds were reduced from 58.3 mph when no animals were detected to 53.1 mph when animals were detected and the warning signs were illuminated. This speed reduction remained relatively constant throughout the 7.5 month study period, with mean speed reductions ranging from 4.5 to 5.8 mph. The LED signs appeared to be even more effective in the evening and overnight, evidenced by mean speed reductions of 4.9 mph. However, there were also issues with the system during the course of the evaluation stemming from false-positive detections. These false detections were the result of a driveway being present within the detection zone which resulted in the beam being broken by vehicles entering and exiting. Consequently, the system did not operate accurately or reliably enough to garner the trust of the driving public. Further, the crop that was an attractant to deer was no longer planted in the adjacent fields, which were fallowed. As a result, the deer population in the area dropped and there was less need for detection at the site.

In general, such a system would not likely be deployed again until a more practical solution is available. For this particular system, the crop that was an attractant was removed, and the targeted deer population became reduced, minimizing the need for the system itself. In addition, the research itself concluded that further investigation of animal warning systems is needed in order to increase their effectiveness through further research and development. This type of work could lead to more practical systems that are vehicle-based rather than roadside.

Specific to the system tested on SR 3, some mechanism to eliminate the false positive detection caused by the driveway within the segment, such as a loop detector, would need to be incorporated. However, such an addition would increase the expense of the system. Maintenance needs for these types of systems also need to be reduced. Finally, the present state of animal warning systems is such that each system uses its own type of warning, including static metal signs, DMS, LED signs, and others. There needs to be a more standardized approach to providing warning in order to maintain driver expectancy and response to the warning itself. In line with this is a need to determine the appropriate spacing of the warnings themselves.

Purpose: Provide warning to motorists that black tailed deer were in the vicinity of the roadside.

Status: Inactive (removed summer of 2013)

Deployed: September, 2009

Location: SR 3 pm 36.5 – 37.3.

Components: Radar detection, system controller, Ethernet communications between signs, LED sign panels, utility power and battery backup.

System Contacts:

Ian Turnbull, P.E.
Chief, Office of ITS Engineering and Support
California Department of Transportation
Telephone: (530) 225-3320
Email: ian_turnbull@dot.ca.gov

Ashkan Sharafsaleh
Sr. Research and Development Engineer
University of California PATH
Telephone: (510) 665-6716
Email: ashcan@path.berkeley.edu

Marcel Huijser
Research Ecologist
Western Transportation Institute
Telephone: (406) 543-2377
Email: mhuijser@coe.montana.edu

Evaluation: http://its.berkeley.edu/publications/UCB/2012/PRR/UCB-ITS-PRR-2012-2.pdf

3.2.2. Sequim Animal Detection System (Washington)

The Sequim animal detection system near Sequim, Washington, is designed to detect the presence of elk near the roadway and provide a warning to motorists. The system was first activated in the fall of 2000. It is located on a three mile long section of U.S. 101 between mileposts 267 and 264. The roadway is high speed (generally 55 mph), two lanes, and is undivided. The system is deployed along a stretch of roadway with wooded and hilly terrain. Local farms attract the elk herds, increasing the potential for animal-vehicle collisions.

The system relies on radio collars applied to 10 percent of the elk herd. Four receivers were placed along the roadway that scan for the radio collar frequency. The detection distance of the radio receivers is approximately 0.25 miles of the roadway. When the receivers pick up the radio collar signals, the system turns on flashing beacons attached to static metal signs along the roadway. Receivers that pick up the signal activate a specific static sign with which they are associated.

No formal system evaluations have been conducted to date to establish its effectiveness. However, it generally appears to work well, at least compared to other technologies. Similar systems have not been deployed elsewhere in the state to date. In the future, improved receivers would be considered since the current effective range of the receivers varies.

Purpose: Provide warning to motorists of the presence of elk near the roadway.

Status: Active

Deployed: Fall, 2000

Location: U.S. 101 mp 267 – 264.

Components: Radio collars applied to the lead cow, radio receivers, static warning signs with flashers.

System Contact:
Kelly McAllister
Fish and Wildlife Biologist
Washington State Department of Transportation
Telephone: (360) 705-7426
Email: mcallke@wsdot.gov

3.2.3. Wenatchee Animal Warning System (Washington)

The Wenatchee animal warning system on U.S. 97A near milepost 206 was designed to detect the presence of large animals near the roadway and provide a warning to motorists. The system was first activated in October, 2002. It is located at milepost 206 on U.S. 97A. The roadway was high speed (generally 55 mph), two lanes, and undivided. Due to issues with system performance, it was removed in the Spring of 2004.

The system relied on infrared beams aimed between points along the roadway. When the beam was broken, the system controller activated flashing yellow beacons on static metal warning signs to alert motorists to animal presence.

During the course of its deployment, the system produced a number of false positives (animals not present but warning signs triggered). The system also turned off the flashing beacons after one minute, even when animals such as deer loitered near the roadside. Based on these issues, the system was viewed as not being successful in meeting its primary objective. Deployment of the system along a segment of roadway with intersections also affected its operation, as vehicles were breaking the infrared beams.

Aside from the observed operational performance of the system, no formal evaluations were conducted. Its use would not likely be considered in the future unless issues related to the false positive detection could be addressed. Additionally, a more conducive test site would be required, specifically one with no intersections present. Future systems should also look at improved power supplies.

Purpose: Provide warning to motorists of the presence of animals near the roadway.

Status: Inactive

Deployed: October, 2000; removed Spring, 2004

Location: U.S. 97A, mp 206.

Components: Infrared beams to detect animal presence, system controller, static warning signs with flashers.

System Contact:
Kelly McAllister
Fish and Wildlife Biologist
Washington State Department of Transportation
Telephone: (360) 705-7426
Email: mcallke@wsdot.gov

3.2.4. Colville Animal Detection System (Washington)

The Colville animal detection system was located on Highway 395 at milepost 290. It was deployed to aid in reducing animal-vehicle collisions by providing drivers with advanced warning that animals were in the area. The system was deployed in June of 2000, and was removed during the spring of 2002. The roadway was a high speed (45+ mph), undivided, two lane route.

The system used two sets of lasers placed on each side of the road that activated flashing beacons on standard static deer warning signs when the beam was broken. The system was battery powered, which presented an issue as the batteries were not connected to the grid or solar panels for charging. This resulted in the system operating for approximately 1 week before losing power. This, combined with laser line of sight and sunlight interference issues, resulted in the system being determined ineffective and subsequently removed.

Based on experience, the system would not be deployed again as designed. Specifically, improvements to the power and detection aspects of the system need to be incorporated. No formal evaluations of the system were conducted.

Purpose: Provide drivers with advanced warning that animals were in the area.

Status: Inactive (2002)

Deployed: 2000

Location: Highway 395, mp 290 near Colville.

Components: Two sets of laser detectors, system controller, static deer warning signs equipped with flashing beacons.

System Contact:
Bill Legg
State ITS Operations Engineer
Washington State Department of Transportation
Telephone: (360) 705-7994
Email: leggb@wsdot.wa.gov

3.2.5. Elk Crossing Warning System (Arizona)

Arizona's elk crossing warning system is located along SR260 east of Payson, Arizona. It has been deployed since 2007 and remains active. The system is designed to warn drivers of large animals (including elk) that may be crossing the road. It can also sense animals as small as coyotes. The route is a high speed (45+ mph) undivided section of roadway. The system was originally developed as part of a five-year research program to address animal vehicle collisions in the area.

The system is comprised of military technology that has been scaled down, specifically infrared sensors. The sensors are located at crossing areas where animals are channeled by right of way and animal fencing. When an animal breaks the infrared beam at a specific crossing area, the system controller triggers flashing beacons (solar powered) that are equipped to static metal warning signs on either side of the road. A radio signal is also sent to portable variable message signs in advance of the crossing to provide additional warning. The static signs are located both 50 feet up and downstream of the crossing itself, while the portable VMS were located 500 feet in advance of the crossing to provide drivers with additional warning.

No formal post-deployment evaluation has been conducted of the system; however, observations by ADOT staff indicate that it has been very effective in reducing animal vehicle collisions. Consequently, similar systems would be deployed using the same equipment in the future if the need arose.

Purpose: Provide drivers with warning that large animals may be crossing the road.

Status: Active

Deployed: 2007

Location: SR 260 east of Payson, Arizona.

Components: Infrared sensors to detect animals entering the crossing, system controllers, radio communications, static metal warning signs equipped with flashers (solar powered), portable variable message signs.

System Contact:
Reza Karimvand
Assistant State Engineer
Arizona Department of Transportation
Telephone: (602) 712-8328
Email: RKarimvand@azdot.gov

3.2.6. Nugget Canyon Flashing Light Animal Sensing Host (Flash) System (Wyoming)

Wyoming's Nugget Canyon flashing light animal sensing host (Flash) system was installed to test a new type of animal detection and warning system. Located along U.S. 30 in the Nugget River Canyon at milepost 30.5, the system was intended to prevent deer-vehicle crashes. It was installed in December, 2000 and removed in May, 2001. It was located along a section of highway that was high speed (45 mph+), two lanes and undivided.

The system used five body heat sensors along each side of the roadway placed at 55 to 60 foot intervals along a 300 foot gap in roadside fencing. When the sensors detected the body heat of animals in the area, the system controller processed the information and activated flashing warning beacons on static signs located 1000 feet in advance of the start of the fencing gap.

While no formal evaluations were conducted, speed reductions by vehicles were observed when the signs were flashing. However, the system had a number of reliability issues and was deactivated after approximately six months. In particular, the body heat sensors experienced degradation from sunlight shortly after installation. This resulted in less accurate detection than intended. Based on this, the system was deemed too unreliable for deployment and has not been used since.

Purpose: Provide drivers with warning that large animals may be crossing the road.

Status: Inactive

Deployed: December, 2000

Location: U.S. 30 in Nugget Canyon, mp 30.5.

Components: Body heat sensors to detect animals, system controller, static metal warning signs equipped with flashing beacons.

System Contact:
Aaron Huffsmith
ITS Research Engineer
Wyoming Department of Transportation
Telephone: (307) 777-4232
Email: aaron.huffsmith@dot.state.wy.us

3.2.7. Animal Crossing Warning System (New Mexico)

New Mexico deployed an animal crossing warning system as part of a reconstruction project on I-40 during 2007. The system is located east of Albuquerque, along a four mile stretch (exact mileposts were not available) of high speed (65+ mph), six lane divided highway passing through the narrow Tijeras Canyon. Food sources to the north of the interstate and water sources to the south make the location a high animal traffic area. The intent of the system was to warn motorists of animal presence and prevent animal-vehicle collisions.

The system is comprised of video detection equipment that senses animal presence, a system controller to process the video data and static warning signs equipped with flashing beacons. Electro-mats have been deployed at different locations to funnel animals to a crossing point. When an animal is detected by video in the vicinity of the mats, the system triggers the warning beacons in the area. Roadside fencing is also used in the area, funneling animals to existing underpasses to cross the roadway.

No formal evaluations of the system have been made to date, but New Mexico DOT staff members have indicated that the video detection equipment is problematic in this specific application. The video cameras are mounted atop 30 foot tall aluminum poles that are not stiff enough for the winds in the area. This leads to reduced detection accuracy when the poles are swaying; in some cases, false detections of trees have been made because of this issue. In the future, thermal detection equipment would be tested, along with the use of steel poles, to address this issue. However, the overall system (Electro-mats, detection, warning and fencing) would be used again in the future.

Purpose: Provide drivers with warning that animals may be crossing the road in the area.

Status: Active

Deployed: 2007

Location: I-40 east of Albuquerque in Tijeras Canyon.

Components: Video detectors to detect animals, system controller, static metal warning signs equipped with flashing beacons.

System Contact:
Mark Fahey, P.E.
Project Development Engineer
New Mexico Department of Transportation
Telephone: (505) 798-6717
Email: mark.fahey@state.nm.us

3.2.8. Roadway Animal Detection System (RADS) (Montana)

The Roadway Animal Detection System (RADS) was installed along U.S. 191 along the western edge of Yellowstone National Park. The system, which was deployed in November of 2004, served as a demonstration test bed for an animal detection and warning system. It was located between mileposts 28 and 29, and was intended to reduce animal-vehicle collisions in that area. The roadway was a high speed (55+ mph), two lane, undivided section. Given the experimental and demonstration nature of the system, it was removed in September of 2008.

The system used microwave signals that were sent between pairs of transmitters and receiver stations to produce a "beam" that was broken when crossed by an animal. When a beam break was detected by the system controller, flashing beacons on static metal warning signs were activated at either end of the corridor. A total of 15 detection zone pairs were set up along the one mile test segment (six on the east side, nine on the west side). System communications between these zones and the system controller was provided via UHF radio, and power was provided by solar panels and batteries.

Evaluations of the system found that vehicle speeds were reduced by 1.52 mph (both directions of travel combined) when the warning beacons were turned on. Large mammal collisions were 66.7 percent lower following deployment of the system. When surveyed, 96 percent of drivers had noticed the system when traveling through the segment.

Despite showing some impacts on vehicle speeds and collision reductions, the system was faced with reliability and robustness issues, particularly the detection system. Additionally, the maintenance efforts required to keep the system functional were more than could be justified, and the system was subsequently removed. These issues would need to be addressed before a similar deployment was considered in the future.

Purpose: Provide drivers with warning that animals may be crossing the road in the area.

Status: Inactive

Deployed: November, 2004 – September, 2008

Location: U.S. 191, milepost 28 – milepost 29.

Components: Microwave detectors, system controller, static metal warning signs equipped with flashing beacons, solar power, batteries.

System Contact:
Marcel Huijser
Research Ecologist
Western Transportation Institute
Telephone: (406) 543-2377
Email: mhuijser@coe.montana.edu

Evaluations:

Phase 1: http://www.oregon.gov/odot/td/tp_res/docs/reports/animalvehicle.pdf

Phase 2: http://www.oregon.gov/ODOT/TD/TP_RES/docs/reports/2009/animal_vehicle_ph2.pdf

3.2.9. State Route 333 Animal Warning System (New Mexico)

An animal warning system has been deployed along New Mexico Route 333, at the underpass of I-40. The system was deployed in 2007 and remains active. It has been used to provide drivers with warning of large animals in the vicinity of the underpass site, which has been used by animals passing from one side of I-40 to the other. The site is on a low speed (45 mph), undivided roadway.

The system uses camera-based motion detectors to identify when large animals are approaching the highway on either side of the right of way. This information is used by the system controller's software to trigger the warning, specifically flashing beacons on static metal warning signs. The system uses radio transmission between its components, and if an animal is detected on one side of the roadway, all warning signs are activated.

Informal monitoring of the system has been performed since deployment. Observations have shown that deer use the underpass regularly, but as far as it is known, only one deer has been killed at the crossing since deployment. The system itself has not performed as expected, as it has received minimal maintenance. The result has been that the flashing beacons remain on for extended periods of time rather than providing warning only when animals are present. Consequently, a different set of system components would be used in the future. For example, different detection technologies would be selected, such as thermal imaging or buried cables to detect movement.

Purpose: Provide drivers with warning that animals may be crossing the road in the area of an Interstate underpass.

Status: Active

Deployed: 2007

Location: State Route 333 at I-40 underpass.

Components: Video-based motion detectors, system controller, static metal signs with flashing beacons, radio transmitters.

System Contact:
Mark Watson
Terrestrial Habitat Specialist, Conservation Services Division
New Mexico Department of Game and Fish
Telephone: (505) 476-8115
Email: mark.watson@state.nm.us

3.3. Curve Warning Systems (Speeds)

Curve warning systems largely target the problem of vehicles approaching a specific curve or curves at unsafe speeds. When a vehicle is detected as approaching at too high of a speed, these systems provide warning and feedback via a variety of mechanisms. These can include posting warning messages to DMS signs, activating flashing LEDs on standard chevron signs, or posting vehicle speeds to an EMS sign. The intent of all of these systems is to slow vehicles down to safely pass through the curve(s).

3.3.1. Sidehill Viaduct Curve Warning System (California)

The Sidehill Viaduct Curve Warning System in Shasta County, California, is designed to warn motorists of an approaching curve that requires reduced speed and to advise them of their current speed; it has been active since 2000. Installed by Caltrans District 2, it is located on Interstate 5 at postmile 29.97. The roadway is high speed (65 mph) and divided.

The system uses a smaller Changeable Message Sign with a graphic that indicates the approaching curve and the recommended speed. A radar unit mounted on the sign measures the approaching vehicle speed, and that speed is displayed in place of the graphic. This sequence repeats as long as traffic is present. When no traffic is present, the sign continuously displays the graphic showing a curve and the recommended speed.

The system has been very effective, with accidents related to excessive speed in the curve significantly reduced since deployment. An early evaluation titled "Sacramento Canyon Curve Warning System Evaluation - Final Report" examined the impacts of the system on vehicle speeds, while a subsequent District 2 Safety Report has conducted an accident analysis over time.

Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere if the need arises, although components from a different manufacturer would be used.

Purpose: Warn motorists of an approaching curve that requires reduced speed and advise them of their current speed.

Status: Active

Deployed: 2000

Location: I-5, pm 29.97.

Components: CMS sign, radar, system controller.

System Contact:
Ian Turnbull, P.E.
Chief, Office of ITS Engineering and Support
California Department of Transportation
Telephone: (530) 225-3320
Email: ian_turnbull@dot.ca.gov

Evaluation: http://www.coe.montana.edu/ce/patm/pubs/files/2000curve.pdf

3.3.2. O'Brien Curve Warning System (California)

The O'Brien Curve Warning System in Shasta County, California, is designed to warn motorists of an approaching curve that requires reduced speed and to advise them of their current speed; it has been active since 2000. Installed by Caltrans District 2, it is located on Interstate 5 at postmile 32.22. The roadway is high speed (65 mph) and divided.

The system uses a smaller Changeable Message Sign with a graphic that indicates the approaching curve and the recommended speed. A radar unit mounted on the sign measures the approaching vehicle speed, and that speed is displayed in place of the graphic. This sequence repeats as long as traffic is present. When no traffic is present, the sign continuously displays the graphic showing a curve and the recommended speed.

The system has been very effective, with accidents related to excessive speed in the curve significantly reduced since deployment. An early evaluation titled "Sacramento Canyon Curve Warning System Evaluation Final Report" examined the impacts of the system on vehicle speeds, while a subsequent District 2 Safety Report has conducted an accident analysis over time.

Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere if the need arises, although components from a different manufacturer would be used.

Purpose: Warn motorists of an approaching curve that requires reduced speed and advise them of their current speed.

Status: Active

Deployed: 2000

Location: I-5, pm 32.22.

Components: CMS sign, radar, controller.

System Contact:
Ian Turnbull, P.E.
Chief, Office of ITS Engineering and Support
California Department of Transportation
Telephone: (530) 225-3320
Email: ian_turnbull@dot.ca.gov

Evaluation: http://www.coe.montana.edu/ce/patm/pubs/files/2000curve.pdf

3.3.3. Salt Creek Curve Warning System (California)

The Salt Creek Curve Warning System in Shasta County, California, is designed to warn motorists of an approaching curve that requires reduced speed and to advise them of their current speed; it has been active since 2000. Installed by Caltrans District 2, it is located on Interstate 5 at postmile 37.47. The roadway is high speed (65 mph) and divided.

The system uses a smaller Changeable Message Sign with a graphic that indicates the approaching curve and the recommended speed. A radar unit mounted on the sign measures the approaching vehicle speed, and that speed is displayed in place of the graphic. This sequence repeats as long as traffic is present. When no traffic is present, the sign continuously displays the graphic showing a curve and the recommended speed.

The system has been very effective, with accidents related to excessive speed in the curve significantly reduced since deployment. An early evaluation titled “Sacramento Canyon Curve Warning System Evaluation Final Report” examined the impacts of the system on vehicle speeds, while a subsequent District 2 Safety Report has conducted an accident analysis over time.

Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere if the need arises, although components from a different manufacturer would be used.

Purpose: Warn motorists of an approaching curve that requires reduced speed and advise them of their current speed.

Status: Active

Deployed: 2000

Location: I-5, pm 37.47.

Components: CMS sign, radar, controller.

System Contact:
Ian Turnbull, P.E.
Chief, Office of ITS Engineering and Support
California Department of Transportation
Telephone: (530) 225-3320
Email: ian_turnbull@dot.ca.gov

Evaluation: http://www.coe.montana.edu/ce/patm/pubs/files/2000curve.pdf

3.3.4. La Moine Road Curve Warning System (California)

The La Moine Road Curve Warning System in Shasta County, California, is designed to warn motorists of an approaching curve that requires reduced speed and to advise them of their current speed; it has been active since 2000. Installed by Caltrans District 2, it is located on Interstate 5 at postmile 49.19. The roadway is high speed (65 mph) and divided.

The system uses a smaller Changeable Message Sign with a graphic that indicates the approaching curve and the recommended speed. A radar unit mounted on the sign measures the approaching vehicle speed, and that speed is displayed in place of the graphic. This sequence repeats as long as traffic is present. When no traffic is present, the sign continuously displays the graphic showing a curve and the recommended speed.

The system has been very effective, with accidents related to excessive speed in the curve significantly reduced since deployment. An early evaluation titled "Sacramento Canyon Curve Warning System Evaluation Final Report" examined the impacts of the system on vehicle speeds, while a subsequent District 2 Safety Report has conducted an accident analysis over time.

Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere if the need arises, although components from a different manufacturer would be used.

Purpose: Warn motorists of an approaching curve that requires reduced speed and advise them of their current speed.

Status: Active

Deployed: 2000

Location: I-5, pm 49.19.

Components: CMS sign, radar, controller.

System Contact:
Ian Turnbull, P.E.
Chief, Office of ITS Engineering and Support
California Department of Transportation
Telephone: (530) 225-3320
Email: ian_turnbull@dot.ca.gov

Evaluation: http://www.coe.montana.edu/ce/patm/pubs/files/2000curve.pdf

3.3.5. Sims Road Curve Warning System (California)

The Sims Road Curve Warning System in Shasta County, California, is designed to warn motorists of an approaching curve that requires reduced speed and advises them of their current speed; it has been active since 2000. Installed by Caltrans District 2, it is located on Interstate 5 at postmile 57.87. The roadway is high speed (65 mph) and divided.

The system uses a smaller Changeable Message Sign with a graphic that indicates the approaching curve and the recommended speed. A radar unit mounted on the sign measures the approaching vehicle speed, and that speed is displayed in place of the graphic. This sequence repeats as long as traffic is present. When no traffic is present, the sign continuously displays the graphic showing a curve and the recommended speed.

The system has been very effective, with accidents related to excessive speed in the curve significantly reduced since deployment. An early evaluation titled "Sacramento Canyon Curve Warning System Evaluation Final Report" examined the impacts of the system on vehicle speeds, while a subsequent District 2 Safety Report has conducted an accident analysis over time.

Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere if the need arises, although components from a different manufacturer would be used.

Purpose: Warn motorists of an approaching curve that requires reduced speed and advise them of their current speed.

Status: Active

Deployed: 2000

Location: I-5, pm 57.87.

Components: CMS sign, radar, controller.

System Contact:
Ian Turnbull, P.E.
Chief, Office of ITS Engineering and Support
California Department of Transportation
Telephone: (530) 225-3320
Email: ian_turnbull@dot.ca.gov

Evaluation: http://www.coe.montana.edu/ce/patm/pubs/files/2000curve.pdf

3.3.6. Ridgewood Grade Curve Warning System (California)

The Ridgewood Grade Curve Warning System in Mendocino County, California, is designed to warn motorists of an approaching curve that requires reduced speed and has been active since 2010. Installed by Caltrans District 1, it is located on U.S. 101 at postmile 99.85. The roadway is low speed (<45 mph), divided and is a 4-lane cross section.

The system uses a Changeable Message Sign with a warning to slow down. A radar unit mounted on the sign measures the approaching vehicle speed, and that speed is processed by the controller. If a vehicle speed exceeds a predetermined value, a message is posted to the CMS saying "Slow Down" in conjunction with a curve symbol.

Based on observations, the system appears to be effective in reducing vehicle speeds and crashes. However, no formal evaluation of the system has been performed to date. There is some concern that the system may lose effectiveness over time with local residents, but tourist traffic will still benefit over time. There were some initial maintenance issues with moisture burning out circuit boards, but these have since been addressed through changes to the controller cabinet. A similar system would be deployed in another location should the need arise, although there is a concern with deploying too many of them. If deployed again, components from a different sign manufacturer and a different type of controller might be used. For the existing system, maintenance staff members selected a signal controller that they were familiar with. However, other controllers may be a better choice for use in this type of system.

Purpose: Provide curve warning to motorists.

Status: Active

Deployed: 2010

Location: U.S. 101, pm 99.85.

Components: Radar unit, signal controller, CMS sign.

System Contact:
Brian Finck, P.E.
California Department of Transportation, District 1
Telephone: (707) 441-5850
Email: brian_finck@dot.ca.gov

3.3.7. Jitney Gulch Curve Warning System (California)

The Jitney Gulch Curve Warning System in Mendocino County, California, is designed to warn motorists of an approaching curve that requires reduced speed; it has been active since 2010. Installed by Caltrans District 1, it is located on U.S. 101 at postmile 92. The roadway is low speed (<45 mph), undivided and is a 4-lane cross section.

The system uses a Changeable Message Sign with a warning to slow down. A radar unit mounted on the sign measures the approaching vehicle speed, and that speed is processed by the controller. If a vehicle speed exceeds a predetermined value, a message is posted to the CMS saying “Slow Down” in conjunction with a curve symbol.

Based on observations, the system appears to be effective in reducing vehicle speeds and crashes. However, no formal evaluation of the system has been performed to date. There is some concern that the system may lose effectiveness over time with local residents, but tourist traffic will still benefit over time. There were some initial maintenance issues with moisture burning out circuit boards, but these have since been addressed through changes to the controller cabinet. A similar system would be deployed in another location should the need arise, although there is a concern with deploying too many of them. If deployed again, components from a different sign manufacturer and a different type of controller might be used. For the existing system, maintenance staff selected a signal controller that they were familiar with. However, other controllers may be a better choice for use in this type of system.

Purpose: Provide curve warning to motorists.

Status: Active

Deployed: 2010

Location: U.S. 101, pm 92.

Components: Radar unit, signal controller, CMS sign.

System Contact:
Brian Finck, P.E.
California Department of Transportation, District 1
Telephone: (707) 441-5850
Email: brian_finck@dot.ca.gov

3.3.8. Big Lagoon Curve Warning System (California)

The Big Lagoon Curve Warning System in Humboldt County, California, is designed to warn motorists of an approaching curve that requires reduced speed; it has been active since 2010. Installed by Caltrans District 1, it is located on U.S. 101 at postmile 111.21. The roadway is low speed (<45 mph), undivided and is a 4-lane cross section.

The system uses a Changeable Message Sign with a warning to slow down. A radar unit mounted on the sign measures the approaching vehicle speed, and that speed is processed by the controller. If a vehicle speed exceeds a predetermined value, a message is posted to the CMS saying "Slow Down" in conjunction with a curve symbol.

Based on observations, the system appears to be effective in reducing vehicle speeds and crashes. However, no formal evaluation of the system has been performed to date. There is some concern that the system may lose effectiveness over time with local residents, but tourist traffic will still benefit over time. There were some initial maintenance issues with moisture burning out circuit boards, but these have since been addressed through changes to the controller cabinet. A similar system would be deployed in another location should the need arise, although there is a concern with deploying too many of them. If deployed again, components from a different sign manufacturer and a different type of controller might be used. For the existing system, maintenance staff selected a signal controller that they were familiar with. However, other controllers may be a better choice for use in this type of system.

Purpose: Provide curve warning to motorists.

Status: Active

Deployed: 2010

Location: U.S. 101, pm 111.21.

Components: Radar unit, signal controller, CMS sign.

System Contact:
Brian Finck, P.E.
California Department of Transportation, District 1
Telephone: (707) 441-5850
Email: brian_finck@dot.ca.gov

3.3.9. Myrtle Creek Advanced Curve Warning System (Oregon)

The Myrtle Creek advanced curve warning system in Myrtle Creek, Oregon, is designed to warn motorists that they are driving too fast for an upcoming curve and to reduce their speed. Installed by the Oregon Department of Transportation in April, 2004, it is located on Interstate 5 between mileposts 107 and 109. The roadway is high speed (65 mph) and divided.

The system uses overhead Dynamic Message Signs to warn motorists that they are driving too fast for an approaching curve. The system uses radar units to measure the speed of approaching vehicles. The measured speeds are then compared by the system controller to specified thresholds. When measured speed is between 50 and 70 mph, a warning message is posted to the overhead DMS along with the measured speed of the vehicle. When speed exceeds 70 mph, an excessive speed message is posted to the DMS indicating the vehicle is traveling over 70 mph.

The system has been very effective in reducing the majority of vehicle speeds. An evaluation of the system found that mean speeds were lower by approximately 3 mph for vehicles traveling southbound and 2 mph for vehicles traveling northbound.

Based on the experiences with this system, this system has also been deployed along I-84 in the Burnt River Canyon and on U.S. 95 in southeast Oregon. These newer deployments use the same technologies and components as the Myrtle Creek system, all of which have worked well over time.

Purpose: Provide warning to motorists that they are driving too fast to safely travel through upcoming curves.

Status: Active

Deployed: 2004

Location: I-5, mp 107 – 109.

Components: Radar units, system controller, overhead Dynamic Message Sign.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

Evaluation: http://www.oregon.gov/ODOT/HWY/ITS/pdfs/benefitsofits/myrtle_creek_report_publish.pdf

3.3.10. Burnt River Canyon Advanced Curve Warning System (Oregon)

The Burnt River Canyon advanced curve warning system south of Baker City, Oregon, is designed to warn motorists that they are driving too fast for an upcoming curve and to reduce their speed. Installed by the Oregon Department of Transportation in the fall of 2012, it is located on Interstate 84 at milepost 340.5. The roadway is high speed (65 mph) and divided.

The system uses overhead Dynamic Message Signs to warn motorists that they are driving too fast for an approaching curve. The system uses radar units to measure the speed of approaching vehicles. The measured speeds are then compared by the system controller to specified thresholds. When measured speed is between 50 and 70 mph, a warning message is posted to the overhead DMS along with the measured speed of the vehicle. When speed exceeds 70 mph, an excessive speed message is posted to the DMS indicating the vehicle is traveling over 70 mph.

While the system is new, a previous evaluation performed for an identical system at Myrtle Creek on I-5 found the system was effective in reducing vehicle speeds. It is expected that this deployment will produce similar results over time. Based on the overall design and components of the system, it is possible that it could be deployed elsewhere in the future, as this system was deployed based on the performance of the Myrtle Creek system. Future deployments would likely use the same technologies and components, all of which have worked well over time.

Purpose: Provide warning to motorists that they are driving too fast to safely travel through upcoming curve.

Status: Active

Deployed: 2012

Location: I-84, mp 340.5.

Components: Radar units, system controller, overhead DMS sign.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

3.3.11. U.S. 95 Advanced Curve Warning System (Oregon)

The U.S. 95 advanced curve warning system in Oregon is located along a remote stretch of the route and is designed to warn motorists that they are driving too fast for an upcoming curve and to reduce their speed. Installed by the Oregon Department of Transportation in April of 2011, it is located on U.S. 95 for the southbound direction of traffic at milepost 51.5. The roadway is two lane, high speed (55 mph) and undivided.

The system uses overhead Dynamic Message Signs to warn motorists that they are driving too fast for an approaching curve. The system uses radar units to measure the speed of approaching vehicles. The measured speeds are then compared by the system controller to specified thresholds. When measured speed is between 30 and 55 mph, a warning message is posted to the overhead DMS along with the measured speed of the vehicle. When speed exceeds 55 mph, an excessive speed message is posted to the DMS indicating the vehicle is traveling over 55 mph.

While the system is new, a previous evaluation performed for an identical system at Myrtle Creek on I-5 found the system was effective in reducing vehicle speeds. It is expected that this deployment will produce similar results over time. Based on the overall design and components of the system, it is possible that it could be deployed elsewhere in the future, as this system was deployed based on the performance of the Myrtle Creek system. Future deployments would likely use the same technologies and components, all of which have worked well over time.

Purpose: Provide warning to motorists that they are driving too fast to safely travel through the upcoming curve.

Status: Active

Deployed: 2011

Location: U.S. 95, mp 51.5.

Components: Radar units, system controller, overhead Dynamic Message Sign.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

3.3.12. Curve Speed Warning System (Washington)

The Washington State Department of Transportation installed two curve speed warning systems as part of a FHWA evaluation of technologies. The first was located on U.S. 101 at milepost 78.4 (southbound only) and the second was on State Route 7 at milepost 30.4 (southbound only). The intention of the systems was to address curve departure crashes by warning vehicles approaching tight curves to slow down. The systems were activated in July of 2008 and were removed in the fall of 2009. Both curve sites were located on high speed (55+ mph), undivided, two lane roadways. The U.S. 101 site had a posted curve speed of 30 mph, while the SR 7 site was posted for 35 mph.

Two different systems from different manufacturers were tested, but their general components and operations were the same. Doppler radar units were used to measure the speed of vehicles approaching the curves (southbound direction of travel only at both sites), supplying these measurements to the system controller. When vehicles were detected to be traveling 7+ mph over the posted advisory speed limit for the curve, a variable message sign was activated to provide warning to the driver. The U.S. 101 sign used a 4 feet by 6 feet sign board that displayed a reverse curve sign symbol and a warning of "Slow Down." The SR 7 sign used a 3 feet by 4 feet sign board that displayed the measured speed of the vehicle along with text that stated "Your Speed," or, if a measured speed exceeded a higher threshold, "Slow Down." Each system used solar power.

To date, an evaluation of speed and crash data has not been completed. Initial evidence indicated that vehicle speeds and crashes fell as the result of the system. The Washington State Highway Patrol has indicated that the U.S. 101 sign was effective in addressing vehicle speeds, based on officers' observations. Additionally, maintenance staff has noted that there has been less need to replace guardrails on the SR 7 curve. However, each sign was shot at and damaged during the course of the deployment. This in part led to the removal of the signs, as the costs to replace components and cover labor expenses repeatedly did not make fiscal sense.

Improvements to the system before considering its use in the future would center on hardening the components. This specifically related to the sign screen (possibly using bulletproof glass) and the solar panels (one panel was stolen during the deployment). Until these types of issues are addressed, it is cost prohibitive to deploy the system as it will require frequent maintenance and part replacement.

Purpose: Provide warning to motorists driving too fast to safely travel through upcoming curves.

Status: Inactive (removed late 2009)

Deployed: 2008

Location: U.S. 101, mp 78.4 (southbound direction); SR 7, mp 30.4 (southbound direction).

Components: Doppler radar units, system controller, Variable Message Signs, solar panels.

System Contact:
Rick Mowlds
State Sign Engineer
Washington State Department of Transportation
Telephone: (360) 705-7988
Email: MOWLDSR@wsdot.wa.gov

3.3.13. King County Curve Warning System (Washington)

King Country, Washington installed two curve speed warning systems on curved sections of roadway with a high incidence of run off the roadway crashes. The roadways included Northeast Novelty Hill Road (east of Redmond) and Lake Holmes Road (east of Auburn), both of which are low speed, undivided two lane roads. Each road traveled along the top of a plateau with posted speed limits of 40 mph before drivers encountered a steep downgrade. The contributing factor in crashes on the downgrade is that vehicles are driving at 35 mph, but they should be driving closer to 25 mph. The systems were activated in 2009 and remain active.

The Novelty Hill Road system is comprised of a microwave vehicle detection system (MVDS) located at the top of the downgrade along with vehicle-activated flashing beacons mounted to a static warning sign. A second static warning sign with beacons is located halfway downhill to the curve and is equipped with a large digital sign board that posts the message "Your Speed Is XX". The speed posted to the sign is measured by the MVDS at the top of the grade. When the measured speed of a vehicle exceeds a specific threshold, the sign board flashes a warning message. A final component of the system is flashing centerline lights that are activated by the speed sign posting a speed/message. The system is solar powered with A.C. and battery backups. The Lake Holmes Road system is identical to the Novelty Hill Road system except that its digital sign board does not include flashing beacons.

To date, no before and after evaluations of the systems have been performed. However, a review of speed measurements recorded by the MVDS units has shown that vehicle speeds over a year after system deployment had fallen by 5 mph. Observations by staff have indicated that the systems appear to have an immediate impact following deployment, followed by speeds going back up over time.

While the systems work well, they are viewed to be complex for the problem they are intended to address. In the future, it is likely that more simplified radar speed signs/trailers would be used rather than the more complex system to achieve the same results. If deployed again, a definite change would be the elimination of flashing centerline lights. These have been expensive and presented maintenance issues related to snow plowing operations. A final change would also be to hard wire (A.C.) the system rather than using solar power, as tree canopy has presented power issues.

Purpose: Provide warning to motorists driving too fast to safely travel through curves on downgrades.

Status: Active

Deployed: August 2012

Location: Northeast Novelty Hill Road (east of Redmond) and Lake Holmes Road (east of Auburn).

Components: Microwave vehicle detection sensors, system controller, static warning signs and flashing beacons, digital sign boards, centerline lights, solar panels.

System Contact:
Henry Perrin
Senior Engineer, Safety Management
King Country Washington Roads Division
Telephone: (206) 263-6138
Email: henry.perrin@kingcounty.gov

3.3.14. Beaverhead Rock Sequential Curve Warning System (Montana)

The Montana Department of Transportation has deployed a sequential curve warning system along MT 41 between mileposts 13.7 and 15.1 in the southwestern corner of the state. The site is high speed (55 mph), with two lanes and an undivided cross section. The site is a problem curve from a geometric perspective, particularly for high profile vehicles, and has been the scene of fatal crashes over time. The intent of the system is to provide a visual warning to vehicles traveling through the curve through the use of flashing LEDs on standard chevron guidance signs. This approach is considered an interim solution until geometric reconstruction can be pursued later in the decade.

The system was deployed in 2013 to address curve crashes while also serving as an experimental test bed for the system itself. It uses radar detectors to sense vehicles approaching the curve from both directions of travel. When a vehicle is detected, the system controller uses a radio-based wireless system between the sequential signs through the curve to activate flashing LEDs on standard chevron signs. A total of 6 directional flashing sign panels are used in the system and are visible to vehicles traveling by direction. Each sign is individually powered by a solar panel and battery combination.

As indicated, the system has been deployed on an interim, experimental basis. As a result, a formal evaluation will be conducted over the lifetime of the system. This evaluation will consist of semi-annual inspections to document the equipment condition and performance, as well as tracking long-term maintenance needs through interviews with staff. Finally, a detailed before and after analysis of crash severity will be completed. This information will assist in determining whether similar systems might be considered at other locations in the future.

Purpose: Provide curve warning to high profile vehicles detected as travelling at an excessive speed.

Status: Active

Deployed: 2013

Location: MT 41, mp 13.7 and 15.1.

Components: Radar speed measurement, laser height measurement, system controller, static warning signs with flashing beacons.

System Contact:
Craig Abernathy
Experimental Project Manager
Montana Department of Transportation
Telephone: (406) 444-6269
Email: cabernathy@mt.gov

3.3.15. SR 17 Dynamic Curve Warning Systems (California)

Caltrans District 5 installed dynamic curve warning systems on State Route 17 for southbound traffic between postmiles 9.5 and 10.0 to address speed-related curve crashes. The first portion of the system, near postmile 9.5, was installed in 2006, while the second system, installed near postmile 10.0, was installed in 2011. The second system was installed to address curve crashes, which had increased since the deployment of the system on the first curve. SR 17 at the curve locations is a high speed (55 mph), divided, four lane road.

The system is straightforward, using radar units on each sign to measure approaching vehicle speeds. This data is sent to the system controller, which determines if the vehicle is approaching the respective curve at too high of a speed. If a high speed is detected, electronic sign boards present the vehicle with a message of “Speed XX” to alert drivers that they are traveling too fast.

While no formal evaluations have been conducted, observations of the systems indicate that they are meeting their intended purpose. This was particularly true of the system deployed in 2006, which helped to reduce crashes at its respective curve. The effectiveness of the system deployed in 2011 is less clear, as other improvements were also made to the site in conjunction with the installation (intersection closed, etc.).

Based on the perceived effectiveness of the system, it was indicated that it would be used in other locations in the future if the need arose. The only proposed change to the system would be to use a different system controller than the one provided by the system vendor.

Purpose: Provide curve warning to vehicles detected as travelling at an excessive speed for upcoming curves.

Status: Active

Deployed: 2006 and 2011

Location: SR 171, pm 9.5 to 10.0.

Components: Radar speed measurement, system controller, electronic warning signs.

System Contact:
Julie Gonzalez
Senior Transportation Electrical Engineer, District 5
California Department of Transportation
Telephone: (805) 549-3048
Email: Julie.m.gonzalez@dot.ca.gov

3.3.16. US 14A Dynamic Curve Warning Systems (Wyoming)

The Wyoming DOT installed a dynamic curve warning system on U.S. 14A for westbound traffic to address speed-related curve crashes on a steep downgrade. The system is located approximately 20 miles east of Lovell and was installed in 2004. U.S. 14A at the curve locations is a high speed (55 mph), undivided, two lane road.

The system is straightforward, using a radar unit to measure approaching vehicle speeds. This data is sent to the system controller which determines if the vehicle is approaching the respective curve at too high of a speed. If a high speed is detected, flashing beacons on static metal signs are activated to alert drivers that they are traveling too fast.

While no formal evaluations have been conducted, observations of the systems indicate that they seem to be effective. While no figures have been compiled, it is believed that the system has helped to reduce crashes at the site. Based on the perceived effectiveness of the system, it was indicated that it would be used in other locations in the future for curve warning if needed. If power and communications at the site were more robust, a more active system would be installed, likely incorporating DMS signs. The only other proposed change to the system is specific to the U.S. 14A site, where there is interest in enhancing the overall safety of the curves by adding catch nets on the runaway truck ramps.

Purpose: Address curve-related crashes on a steep grade.

Status: Active

Deployed: 2004

Location: US 14A, unspecified milepost.

Components: Radar speed measurement, system controller, static metal signs with flashing beacons.

System Contact:
Aaron Huffsmith
ITS Research Engineer
Wyoming Department of Transportation
Telephone: (307) 777-4232
Email: aaron.huffsmith@dot.state.wy.us

3.3.17. Apple Bend / Spanish Fork Canyon Curve Speed Warning System (Utah)

The Utah DOT deployed a curve speed warning system along U.S. 6 for eastbound traffic in 2006. The system aimed to address curve crashes related to speed, including crashes involving high profile vehicles. It was located along a low speed (40 mph), undivided, two lane road at milepost 192.2. The system remains active to date.

The system is straightforward, using a radar unit to measure approaching eastbound vehicle speeds. This data is sent to the system controller, which determines if the vehicle is approaching the curve at too high of a speed. If a high speed is detected, an EMS sign is activated, presenting the message “Your Speed is XX Reduce to 40 MPH.” The entire system is solar powered due to a lack of grid-based power at the site.

While no formal evaluations have been conducted, observations of the system indicate that it seems to be effective. The state highway patrol has indicated that there have been no crashes at the site since the system was deployed. Based on the perceived effectiveness of the system, it has been used again on Highway 6 near the town of Eureka. Power at the site has been a challenge, with a solar system used. Overall, solar power works well, requiring the usual battery changes and other normal maintenance. Based on the performance of the system and its straightforward components, no changes would be made to future deployments.

Purpose: Address crashes on a curve, including high profile vehicles, where speed was a factor.

Status: Active

Deployed: 2006

Location: U.S. 6, mp 192.2 (eastbound).

Components: Radar speed measurement, system controller, EMS sign, solar power.

System Contact:
Brian Phillips
Region Traffic Operations Engineer
Utah Department of Transportation
Telephone: (801) 227-8019
Email: brianphillips@utah.gov

3.3.18. Highway 6 Curve Speed Warning System (Utah)

The Utah DOT deployed a curve speed warning system along Hwy 6 traffic in 2013. The system is the same as was used on U.S. 6 at Apple Bend and addresses curve crashes related to speed. The site was located along a low speed (<45 mph), undivided, two lane road at milepost 141.5. The system remains active to date.

The system is straightforward, using a radar unit to measure approaching eastbound vehicle speeds. This data is sent to the system controller, which determines if the vehicle is approaching the curve at too high of a speed. If a high speed is detected, an EMS sign is activated, presenting the message “Your Speed is XX Reduce to 40 MPH.”

Due to the recent deployment of the system, no formal evaluation has been performed to date. Based on historical performance, the system components are the same as those used in the previous system. Given that this is a follow-up deployment, the same system would be used again elsewhere if the need arose.

Purpose: Address crashes on a curve where speed was a factor.

Status: Active

Deployed: 2006

Location: Hwy 6, mp 141.5.

Components: Radar speed measurement, system controller, EMS sign, solar power.

System Contact:
Brian Phillips
Region Traffic Operations Engineer
Utah Department of Transportation
Telephone: (801) 227-8019
Email: brianphillips@utah.gov

3.3.19. SR 7 Sequential Dynamic Curve Speed Warning System (Washington)

As part of a research evaluation, a sequential dynamic curve warning system was deployed on SR 7 in Washington State during the summer of 2012. The system targeted curve-related crashes at the site, located at milepost 31.7. The site was a high speed (50 mph), undivided, two lane site, with the curve itself signed for 20 mph.

The system uses radar units to measure vehicle speeds, with a system controller evaluating the speed data to determine if flashing LEDs on standard metal chevron signs should be activated. The LEDs are activated when a vehicle speed is detected to be at or above the advisory speed of the curve. The system uses solar power, and wireless communications are employed between the controller and the signs.

Given that the deployment was part of a larger research effort, an evaluation remains ongoing. However, some initial reductions in mean speeds at the site were observed (a drop of 1.4 mph). Additionally, vehicles exceeding the posted advisory speed have been reduced. Since the system is still being evaluated, it is not clear whether it would be recommended for use in other locations in the future. Similarly, it cannot be determined what components might be changed in any future deployments.

Purpose: Address crashes on a curve where speed was a factor.

Status: Active

Deployed: 2012

Location: SR 7, mp 31.7.

Components: Radar speed measurement, system controller, standard chevron signs with flashing LEDs, solar power, wireless communications.

System Contact:
Rick Mowlds
State Sign Engineer
Washington State Department of Transportation
Telephone: (360) 705-7988
Email: MOWLDSR@wsdot.wa.gov

Evaluation: Smadi, Omar, Neal Hawkins, Shauna Hallmark, Skylar Knickerbocker. Evaluation of the TAPCO Sequential Dynamic Curve Warning System. Report FHWA-HIF-13-040, Federal Highway Administration, Washington, D.C., June 2013.

3.3.20. SR 203 Sequential Dynamic Curve Speed Warning System (Washington)

As part of a research evaluation, a sequential dynamic curve warning system was deployed on SR 203 in Washington State during the summer of 2012. The system targeted curve-related crashes at the site, located at milepost 20.88. The site was a high speed (55 mph), undivided, two lane site.

The system uses radar units to measure vehicles speeds, with a system controller evaluating the speed data to determine if flashing LEDs on standard metal chevron signs should be activated. The LEDs are activated when a vehicle speed is detected to be at or above the advisory speed of the curve. The system uses solar power, and wireless communications are employed between the controller and the signs.

Given that the deployment was part of a larger research effort, an evaluation remains ongoing. However, some initial reductions in mean speeds at the site were observed one month following deployment (a drop of 0.1 mph). Additionally, the number of vehicles exceeding the advisory speed at the site by 10 mph or greater has fallen. Since the system is still being evaluated, it is not clear whether it would be recommended for use in other locations in the future. Similarly, it cannot be determined what components might be changed in any future deployments.

Purpose: Address crashes on a curve where speed was a factor.

Status: Active

Deployed: 2012

Location: SR 203, mp 20.88.

Components: Radar speed measurement, system controller, standard chevron signs with flashing LEDs, solar power, wireless communications.

System Contact:
Rick Mowlds
State Sign Engineer
Washington State Department of Transportation
Telephone: (360) 705-7988
Email: MOWLDSR@wsdot.wa.gov

Evaluation: Smadi, Omar, Neal Hawkins, Shauna Hallmark, Skylar Knickerbocker. Evaluation of the TAPCO Sequential Dynamic Curve Warning System. Report FHWA-HIF-13-040, Federal Highway Administration, Washington, D.C., June 2013.

3.3.21. SR 9 Sequential Dynamic Curve Speed Warning System (Washington)

As part of a research evaluation, a sequential dynamic curve warning system was deployed on SR 9 in Washington State during the summer of 2012. The system targeted curve-related crashes at the site, located at milepost 50.16. The site was a high speed (50 mph), undivided, two lane site, with the curve itself signed for 40 mph.

The system uses radar units to measure vehicles speeds, with a system controller evaluating the speed data to determine if flashing LEDs on standard metal chevron signs should be activated. The LEDs are activated when a vehicle speed is detected to be at or above the advisory speed of the curve. The system uses solar power, and wireless communications are employed between the controller and the signs.

Given that the deployment was part of a larger research effort, an evaluation remains ongoing. However, some initial reductions in mean speeds at the site were observed one month following deployment (a drop of 0.9 mph). Additionally, the number of vehicles exceeding the advisory speed at the site by 10 mph or greater has fallen. Since the system is still being evaluated, it is not clear whether it would be recommended for use in other locations in the future. Similarly, it cannot be determined what components might be changed in any future deployments.

Purpose: Address crashes on a curve where speed was a factor.

Status: Active

Deployed: 2012

Location: SR 9, mp 50.16.

Components: Radar speed measurement, system controller, standard chevron signs with flashing LEDs, solar power, wireless communications.

System Contact:
Rick Mowlds
State Sign Engineer
Washington State Department of Transportation
Telephone: (360) 705-7988
Email: MOWLDSR@wsdot.wa.gov

Evaluation: Smadi, Omar, Neal Hawkins, Shauna Hallmark, Skylar Knickerbocker. Evaluation of the TAPCO Sequential Dynamic Curve Warning System. Report FHWA-HIF-13-040, Federal Highway Administration, Washington, D.C., June 2013.

3.4. Traffic/Queue Warning Systems

Traffic and queue warning systems have been used to provide warning of slowed or stopped traffic ahead. The primary target of these systems is to reduce rear-end collisions that are the result of vehicles being caught unaware when reaching the back of a queue or encountering slowed traffic. These deployments have typically been made at locations where sight distance restrictions limit the ability of approaching vehicles to see slowed or stopped traffic ahead and react in time.

3.4.1. Walker Road Traffic Warning System (California)

The Walker Road Traffic Warning System on U.S. 101 in Mendocino County, California, is designed to warn motorists of slowed/stopped traffic ahead. It has been active since the mid-2000s. The system warns upstream vehicles of traffic ahead via messages posted to CMS signs. Installed by Caltrans District 1, it is located at postmile R42.61. The roadway is a low speed (35 mph), two lane, undivided section.

The system uses a loop detector to sense when traffic is slowed or stopped at an initial point, with that data processed through a signal controller. Based on the presence of slowed or stopped vehicles, the controller activates the CMS sign upstream. When turned on, the sign displays a message that says “Slow Moving Traffic.”

The system has been effective based on observations, although no formal safety evaluations have been performed to date. Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere. However, there is some concern that deploying too many of these types of systems could result in drivers not paying attention to them. Future improvements would include consideration of a different sign manufacturer and type of controller. At present, a modified signal controller is used, because that is what maintenance staff members are most familiar with, but other controllers might be better suited for the application.

Purpose: Warn motorists of slowed/stopped traffic ahead.

Status: Active

Deployed: mid 2000s

Location: U.S. 101, pm R42.610

Components: Loop detector, signal controller, CMS sign.

System Contact:
Brian Finck, P.E.
California Department of Transportation District 1
Telephone: (707) 441-5850
Email: brian_finck@dot.ca.gov

3.4.2. Confusion Hill Traffic Warning System (California)

The Confusion Hill Traffic Warning System on U.S. 101 in Mendocino County, California, is designed to warn motorists of slowed/stopped traffic ahead at a site where there is a large amount of tourist/campground traffic. It has been active since 2009. The system warns upstream vehicles of traffic ahead via messages posted to CMS signs. Installed by Caltrans District 1, it is located at postmile 99.3. The roadway is a low speed (35 mph), two lane, undivided section.

The system uses a loop detector to sense when traffic is slowed or stopped at an initial point, with that data processed through a signal controller. Based on the presence of slowed or stopped vehicles, the controller activates the CMS sign upstream. When turned on, the sign displays a message that says “Slow Moving Traffic.”

The system has been effective based on observations, although no formal safety evaluations have been performed to date. Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere. However, there is some concern that deploying too many of these types of systems could result in drivers not paying attention to them. Future improvements would include consideration of a different sign manufacturer and type of controller. At present, a modified signal controller is used because that is what maintenance staff members are most familiar with, but other controllers might be better suited for the application.

Purpose: Warn motorists of slowed/stopped traffic ahead.

Status: Active

Deployed: 2009

Location: U.S. 101, pm 99.3.

Components: Loop detector, signal controller, CMS sign.

System Contact:
Brian Finck, P.E.
California Department of Transportation District 1
Telephone: (707) 441-5850
Email: brian_finck@dot.ca.gov

3.4.3. Marysville Queue Warning System (California)

The Marysville Queue Warning System on State Route 70 in Yuba County, California, is designed to warn northbound motorists of slowed/stopped traffic ahead. It has been active since 2007. The location is a speed transition area, where traffic can back up over a bridge, with the resulting queue catching approaching vehicles by surprise and resulting in rear end crashes. Installed by Caltrans District 3, it is located on State Route 70 at postmiles 13.5 (initial loop detector), 11.17 (second loop detector and first sign) and 9.67 (second sign). The roadway is a high speed freeway (65 mph) to low speed arterial (35 mph) transition and divided.

The system uses loop detectors to sense when traffic is slowed or stopped at an initial point, with that data processed through a controller using ramp metering software to determine whether a specific threshold is met. When certain traffic conditions are present, a contact closure is triggered and the first CMS sign (pm 11.17) is activated. When these conditions are detected by a second loop at pm 11.17, a second contact closure is triggered, and the second CMS sign at pm 9.67 is turned on. When traffic conditions for queuing have dissipated, the system works in reverse to turn the signs off. Wireless communications are employed between the controller and signs. When turned on, each sign displays a message that says “Caution Stopped Traffic Ahead.”

The system has been effective based on observations, although no formal safety evaluations have been performed to date. Based on the experiences with this system, it is possible that this type of system would be deployed again elsewhere if the need arises. Future improvements would include the potential use of radar sensors instead of loops to facilitate quicker deployment. Additionally, more user friendly reporting mechanisms would be incorporated into the system. These include notifications to operators when the system turns on or off (e.g., via email) and a positive feedback mechanism in the CMS signs when the message or the sign does not display (e.g., power outages, communications being down, etc.).

Purpose: Warn motorists of slowed/stopped traffic ahead where view is obstructed by bridge.

Status: Active

Deployed: 2007

Location: SR 70, pm 13.5, 11.7 and 9.67.

Components: Loop detectors, controller, ramp metering software, CMS signs, wireless communications.

System Contact:
Brian Simi, P.E.
Chief, Electrical Systems Branch
California Department of Transportation District 3
Telephone: (916) 859-7960
Email: brian_simi@dot.ca.gov

3.4.4. Dundee Queue Detection System (Oregon)

The Dundee queue detection system on State Route 99E, near Dundee, Oregon, was designed to warn motorists of slowed/stopped traffic ahead on a hilly section of roadway with reduced visibility. It was installed in 1999 but has since been deactivated. The system warned upstream vehicles of traffic ahead via overhead warning signs with flashers. The roadway was a high speed (45 mph), two lane, undivided section located between mileposts 27.6 and 28.2.

The system used a series of loop detectors to sense when traffic was slowed or stopped in the lane approaching the intersection at the top of a hill (the point where the view of vehicles was obstructed), with that data processed through a controller. When the controller determined the presence of a vehicle for a predetermined period of time, it turned the warning sign flashers on. The overhead static warning signs were in advance of the hill to warn drivers of slowed or stopped traffic ahead.

The system was generally effective based on observations, with 9 crashes occurring in a 10 month period prior to system installation and 4 crashes observed during the 10 months after installation. While the system appeared to meet the targeted objective of addressing rear-end crashes, similar systems have not been deployed again elsewhere. During the time the system was active, the interconnection between the system controller cabinet and the upstream warning signs saw voltage drops due to the distance between these points. Future improvements to similar systems should consider this issue and use solar power for remote static signs/flashers and wireless signals for system activation.

Purpose: Reduce rear-end crashes on a hilly section of roadway with reduced visibility of queued vehicles at a signal.

Status: Inactive

Deployed: 1999

Location: SR 99E, mp 27.6 - 28.2.

Components: Loop detectors, system controller, overhead warning signs with flashers.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

3.4.5. Eugene Queue Detection System (Oregon)

The Eugene queue detection system on the Delta Highway in the Eugene, Oregon area, was designed to detect stopped traffic on a high speed roadway that has a tendency to queue up and to warn motorists of slowed/stopped traffic ahead. It was installed in 2011 and provided warning to upstream vehicles via Dynamic Message Signs. The roadway was a high speed (>45 mph) divided section located between milepost 1.20 and the Beltline interchange (State Highway 569).

The system uses a series of traffic sensors to determine when traffic is beginning to queue up, with that data processed through a controller. When the controller determined the queuing traffic, it activates a warning message to the DMS signs. The system is still relatively new, and there has not been much feedback from ODOT personnel regarding its effectiveness. However, there is some confidence in the system and its components, as a similar system is being deployed for a queuing problem on OR 217.

Purpose: Reduce rear-end crashes on a high speed road with reduced visibility of queued vehicles stopped ahead.

Status: Active

Deployed: Fall 2011

Location: Delta Highway, between mp 1.20 and the Beltline interchange (State Highway 569).

Components: Traffic sensors, system controller, Dynamic Message Signs.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

3.4.6. Waldo Grade Queue Warning System (California)

Until 2003, Caltrans District 4 maintained a queue warning system in the northbound direction of U.S. 101 on Waldo Grade from the Golden Gate Bridge until the top of the grade at the tunnel. The purpose of the system was to provide warning of slow moving vehicles (buses) ahead on the grade during rush hour. U.S. 101 at the site was a high speed (55 mph), multilane divided highway.

The system consisted of in-pavement sensors to detect traffic conditions, system controllers and static metal warning signs with flashing beacons. When slow moving traffic was detected in the dedicated bus lane, specific beacons on signs in its proximity were activated. As indicated previously, the system has been removed as its need was reduced over the years.

No formal evaluations of the system were made, but it was viewed as being effective in providing warning and reducing crashes. In light of meeting its intended purpose, similar systems would be used again in the future if the need arose. It is not clear what changes to sensors, controllers, or other equipment might be made given how long ago the system was developed.

Purpose: Address queuing issues related to slow moving buses in a dedicated bus lane during rush hour.

Status: Removed 2003

Deployed: Unknown

Location: U.S. 101 on Waldo Grade (northbound immediately after the Golden Gate Bridge.

Components: Traffic sensors, system controller, static metal signs with flashing beacons.

System Contact:
Charles Price
Office Chief, District 4
California Department of Transportation
Telephone: (510) 286-4478
Email: Charles.price@dot.ca.gov

3.4.7. I-580 Queue Warning System (California)

Until 2003, Caltrans District 4 maintained a queue warning system in the eastbound direction of I-580 at the Hopyard interchange. The purpose of the system was to provide warning of queue backups at the interchange that could extend to the mainline. The site was located at postmile 45 on I-580, a high speed (65 mph), multilane divided highway.

The system consisted of magnetometers to detect traffic conditions, a system controller and static metal warning signs with flashing beacons. When slow moving traffic was detected, specific beacons were activated. The system was removed in approximately 2003 for unknown reasons.

No formal evaluations of the system were made, so its effectiveness is unknown. Systems incorporating newer components and sensors have been developed over time, so the approach taken in building this particular system would likely not be used again.

Purpose: Address queuing issues related to an interchange.

Status: Removed 2003

Deployed: Unknown

Location: I-580, pm 45.

Components: Magnetometers, system controller, static metal signs with flashing beacons.

System Contact:
Charles Price
Office Chief, District 4
California Department of Transportation
Telephone: (510) 286-4478
Email: Charles.price@dot.ca.gov

3.4.8. U.S. 101 Queue Warning System (California)

Caltrans District 4 has deployed a queue warning system in the southbound direction of U.S. 101 at postmile 457 to address interchange ramp-related queuing. The site is a high speed (65 mph), multilane divided highway and the system remains active to date. The system uses loop detectors to establish when queuing is occurring. Once a queue is detected, the system controller activates a warning message on an EMS sign.

No formal evaluations of the system have been made, but from general observations, it has been effective. Based on this perceived effectiveness, a similar system would be used in the future if the need arose. Given the basic nature of the system and its components, no changes or improvements would be made to a future deployment.

Purpose: Address queuing issues related to an interchange.

Status: Active

Deployed: Unknown

Location: U.S. 101, pm 457.0.

Components: Loop detectors, system controller, EMS sign.

System Contact:
Charles Price
Office Chief, District 4
California Department of Transportation
Telephone: (510) 286-4478
Email: Charles.price@dot.ca.gov

3.5. Variable Speed Limit Systems

Variable speed limit systems, while in wider use throughout the western U.S., are not typically automated in the sense that they are free of TMC interaction and activation. In general, such systems are not entirely automated because of the desire by many agencies to maintain some hands-on control and oversight of the system while it is operating. In the case of the systems discussed here, similar oversight is maintained, but the VSL operates in an automated manner without activation from an operator (although such a capability is built into the system if the need should arise during an emergency).

3.5.1. Urban Advanced Traffic Management System (Washington)

The Washington State DOT has installed automated Advanced Traffic Management Systems (ATMS) along several roadways in the Seattle area. These include I-5 between mileposts 157.23 and 164.46 (northbound direction), I-90 between mileposts 2.81 and 11.33 (eastbound direction), I-90 between mileposts 11.71 and 3.19 (westbound direction) and on SR 520 for 11 miles. All of these roadways are high speed and divided, with installations made in locations with high accident rates and large volumes of commuter traffic.

The system is designed to provide advance notice to drivers of lane closures or merging by travel lane based on prevailing conditions ahead. Fiber optic/LED signs are positioned over each lane at ½ mile intervals, displaying the lane closure or merge conditions that are ahead for that lane. The uprights to each overhead mast are equipped with a full variable message sign that provides messages with details related to why a lane change is occurring. The data to support the system is obtained via loop detectors and supplemented by sidefire radar units. While the system is automated, conditions are also monitored via CCTV in the traffic management center.

WSDOT is still evaluating the effectiveness of the system, particularly to determine whether crashes have been reduced. Since the evaluation is ongoing, it is not clear whether the system will be expanded or deployed elsewhere, or what changes or improvements would be made.

Purpose: Reduce accident rates by providing advanced notice of lane closures or merging conditions ahead.

Status: Active

Deployed: October and November, 2009

Location: I-5, mp 157.23-164.46 (northbound direction), I-90, mp 2.81-11.33 (eastbound direction), I-90, mp 11.71-3.19 (westbound direction), SR 520.

Components: Loop detectors, sidefire radar, control computers, fiber optic/LED signs and masts over lanes at ½ mile intervals, VMS at roadside on each mast structure.

System Contact:
Bill Legg
State ITS Operations Engineer
Washington State Department of Transportation
Telephone: (360) 705-7994
Email: leggb@wsdot.wa.gov

Evaluation: http://www.wsdot.wa.gov/research/reports/fullreports/511.1.pdf

3.5.2. Snoqualmie and Stevens Pass Winter Weather Variable Speed Limit Systems (Washington)

The Snoqualmie Pass and Stevens Pass variable speed limit system modify speed limits based on prevailing weather conditions. They were installed specifically to address crashes that occur during winter weather events on each pass, where drivers often traveled too fast for conditions. The Snoqualmie Pass system was installed in 1997 between mileposts 33 and 71, while the Stevens Pass system was installed in late 2010 (with upgrades in 2012) between mileposts 57.49 and 105.31. Each of these systems at present is operator-controlled from a central location, but the long-term intent is to convert them to automated operations.

The system uses Road Weather Information System data and sensors to detect present weather and traffic conditions, with that data processed through a central computer. Based on the current conditions detected, the computer determines a "safe speed" that is reported to a DOT operator who makes a decision on the speed limit that will be posted. The selected speed limit is posted to different variable speed limit signs and Variable Message Signs spread throughout each corridor.

The Snoqualmie Pass system has been effective based on evaluation results, while the Stevens pass system has anecdotally shown to be effective through observations of reduced crashes. Based on the experiences with these systems, it is possible that similar ones could be deployed again elsewhere. In fact, the performance of the Snoqualmie Pass system led to the installation of the Stevens Pass system. However, as noted in prior text, the system at present is operator-controlled. The expectation is that it will eventually become automated, with the computer determining and posting a speed limit based on prevailing conditions. Consequently, full automation is a future improvement that will be incorporated in the system.

Purpose: Reduce accident rates during winter weather.

Status: Active

Deployed: 1997 (I-90); 2011 (US-2)

Location: I-90, mp 33-71; U.S.-2, mp 57.49 – 105.31.

Components: Road Weather Information System (RWIS) sensors, central control computer, Variable Speed Limit signs.

System Contact:
Bill Legg
State ITS Operations Engineer
Washington State Department of Transportation
Telephone: (360) 705-7994
Email: leggb@wsdot.wa.gov

Evaluation: http://www.wsdot.wa.gov/research/reports/fullreports/511.1.pdf

3.5.3. Staley's Junction Variable Speed System (Oregon)

The Staley's Junction variable speed system changes the posted speed limit on U.S. 26 depending on peak traffic periods in order to create more gap opportunities for left turning traffic on OR 47. The system was installed specifically to address crashes involving left turning vehicles from OR 47 during those peak traffic periods, particularly during the summer months when tourism traffic is increased. The system is located at the intersection of U.S. 26 and OR 47, near Buxton, Oregon and was installed in 2010.

The system is entirely automated, using traffic sensors on U.S. 26 to detect peak periods. When traffic peaks are detected and processed by the system controller, an appropriate speed limit is posted on variable speed limit signs on U.S. 26. The normal posted speed is 50 mph and can be lowered as far as 30 mph, depending on traffic volumes. This drop in posted speed limit is aimed to create left turning gaps for traffic on OR 47. In addition to variable speed signs, flashing warning signs are also activated to alert drivers when the system has lowered the speed limit. When traffic volumes drop back to an average level, the normal posted speed limit is resumed.

No formal evaluation of the Staley's Junction system has been performed to date. However, a review of data collected and recorded by the system has shown that 85^{th} percentile and average vehicle speeds on U.S. 26 are lower when the system is operating. This indicates that drivers are observing the posted speed limit and lowering their speed accordingly. Lower side street delay (OR 47) has also been observed, as have smaller left turning queues. Consequently, it appears that the system is working as intended. Based in part on the observations made to date from this system, other forms of variable speed limit systems are being planned for use in Oregon. Given the newness of the system, no changes to the current system or its sensors/components have been identified to date.

Purpose: Reduce intersection crashes caused by a lack of gaps for left turning vehicles from OR 47 to U.S. 26.

Status: Active

Deployed: 2010

Location: Intersection of U.S. 26 and OR 47 near Buxton, Oregon.

Components: Traffic sensors, central controller, Variable Speed Limit signs, flashing warning signs.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

3.6. Wind Warning Systems

Wind warning systems typically measure wind speed in an area where high winds are recurring and activate a warning when necessary. The target of such systems can vary from a general warning to all vehicles in a high wind area to a specifically targeted group, such as high profile vehicles (i.e., tractor-trailer units or recreational vehicles). Regardless, the intent is to provide wind warning and illicit a response, such as a halt in traffic until the wind condition diminishes.

3.6.1. South Coast Wind Warning System (Oregon)

The South Coast wind warning system was installed along U.S. 101 between Port Orford and Gold Beach, Oregon, to provide motorists with a warning of high winds along a 30 mile stretch of roadway. The system, which was installed in early 2004 and is located between mileposts 300 and 330, uses an anemometer to measure wind speeds at a central point (Humbug Mountain). This information is provided to the system controller, which activates flashers on static wind warning signs at each end of the corridor when sustained wind speeds exceed 30 mph. When sustained wind speeds fall to 20 mph, the sign flashers are turned off.

In terms of effectiveness, a survey of drivers on the corridor found that the information provided by the system was useful. Approximately 84 percent of surveyed drivers indicated that they believed the system provided accurate information and warning, and 75 percent of drivers had at least seen/observed the sign. The full report, which discusses the system, along with similar ones, is provided at the link below. Based on these observations, as well as the performance of the system over time, ODOT has indicated they would deploy similar systems elsewhere if needed. The system itself is simple in terms of components, and no changes or improvements would be made if deployed again in the future.

Purpose: Warn motorists of high wind speeds along a 30 mile stretch of U.S. 101 along the Oregon coast.

Status: Active

Deployed: 2004

Location: U.S. 101 between mp 300 – 330.

Components: Anemometer, controller, radio communications, static warning signs with flashing beacons.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

Evaluation:
http://www.westerntransportationinstitute.org/documents/reports/426705_Final_Report.pdf

3.6.2. Yaquina Bay Wind Warning System (Oregon)

The Yaquina Bay wind warning system was installed along U.S. 101 between mileposts 141.27 and 142.08, to provide motorists with a warning of high winds on the bridge across the bay. It also helped to eliminate the risks associated with ODOT maintenance staff visiting the site to measure wind speeds and activate warnings during wind events. The system, which was installed in early 2004, uses an anemometer to measure wind speeds at the bridge. This information is provided to the system controller, which activates flashers on static wind warning signs at each end of the bridge when sustained wind speeds of 35 mph or gusts of 40 mph are measured. When sustained wind speeds fall to 25 mph or gusts, the sign flashers are turned off.

A survey of drivers at the site found that the information provided by the system was useful. Approximately 80 percent of surveyed drivers indicated that they believed the system provided accurate information and warning, and 60 percent of drivers had at least seen/observed the sign. The full report, which discusses the system, along with similar ones, is provided at the link below. Based on these observations, as well as the performance of the system over time, ODOT has indicated they would deploy similar systems elsewhere if needed. The system itself is simple in terms of components, and no changes or improvements would be made if deployed again in the future.

Purpose: Warn motorists of high wind speeds on the Yaquina Bay bridge and eliminate the need for ODOT staff to go to the site to measure wind speeds and activate warning signs.

Status: Active

Deployed: 2004

Location: U.S. 101 between mp 141.27 – 142.08.

Components: Anemometer, controller, radio communications, static warning signs with flashing beacons.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

Evaluation:
http://www.westerntransportationinstitute.org/documents/reports/426705_Final_Report.pdf

3.6.3. Dual Use Safety Technology (DUST) Warning System (Arizona)

The Arizona DOT's Dual Use Safety Technology (DUST) was installed along I-10 in Cochise County (passing through the Texas Canyon mountain pass, and located between the communities of San Simon and Bowie) to provide motorists with a warning of low visibility and high winds. The system, which was activated in 2012, measures wind speeds and visibility. When adverse conditions are detected, messages are posted to dynamic message signs and highway advisory radio to warn drivers. Depending on how severe conditions are, road closures and detours may also be implemented.

The system is comprised of anemometers, wind speed indicators, visibility sensors, cameras, a controller, DMS signs equipped with flashing beacons and HAR. When the system controller determines wind or visibility conditions have deteriorated, the system controller activates the DMS and HAR messages. The system also sends an email alert to highway patrol and Arizona DOT personnel alerting them to the existing conditions and system activation.

The DUST system is the first such system that has been developed and deployed in the U.S. Consequently, the newness of the system has precluded a formal evaluation of performance to date. However, based on observations, the system is working as intended. Although still new, ADOT personnel have indicated a willingness to consider the use of the system in other locations. However, any prospective improvements or changes that are needed to the system in future applications have not yet been identified.

Purpose: Warn motorists of low visibility and/or high wind speeds through Texas Canyon pass along I-10.

Status: Active

Deployed: 2012

Location: I-10 across Texas Canyon Pass between San Simon and Bowie in Cochise County.

Components: Anemometers, wind speed indicators, visibility sensors, cameras, controller, DMS signs equipped with flashing beacons and HAR.

System Contact:
Reza Karimvand
Assistant State Engineer
Arizona Department of Transportation
Telephone: (602) 712-8328
Email: RKarimvand@azdot.gov

Evaluation: http://ops.fhwa.dot.gov/publications/fhwahop12046/rwm04_arizona.htm

3.6.4. Vantage Bridge Wind Warning System (Washington)

The Vantage Bridge wind warning system is located on I-90 at milepost 137.19. The system provides warning to trucks about high winds on the bridge and was installed in response to several blow-over truck crashes that were occurring each year. The warning is accomplished via a static sign equipped with flashers, which turn on when high winds are present to provide warning to trucks to turn around and not use the bridge. The system was deployed in 2009.

The system is straightforward and consists of a weather station to detect wind, a system controller, and static signage equipped with flashers to notify truck drivers of the wind. No formal evaluations of the system have been made to date, but through observation, the system works as intended. However, there have still been truck blow-over crashes involving drivers that have ignored the signs and warning.

Similar systems might be considered in other locations, depending on the situation and needs. However, the proper location of the weather station equipment must be considered to prevent it from being hit in a crash. This was an issue with the Vantage Bridge system, where a crash damaged the weather station, requiring it to be moved. Aside from this issue, the system components were straightforward and no improvements or changes would be made in any future deployment.

Purpose: Provide truck drivers with a high wind warning prior to entering the Vantage Bridge on I-90.

Status: Active

Deployed: 2009

Location: I-90, mp 137.19 (Vantage Bridge).

Components: Weather station for wind detection, controller, static warning signs equipped with flashing beacons.

System Contact:
Bill Legg
State ITS Operations Engineer
Washington State Department of Transportation
Telephone: (360) 705-7994
Email: leggb@wsdot.wa.gov

3.6.5. I-10 Wind Warning System (New Mexico)

New Mexico has installed a wind warning system along I-10 to provide drivers with notification of dust storms. The system provides warning to drivers via highway advisory radio (HAR) and flashing beacons on static signs. The weather sensors (RWIS) are located at milepost 11 and milepost 12, while the HARs and beacon-equipped signs are located east and west of Lordsburg, east and west of Deming, and west of Las Cruces. The roadway is high speed (65+ mph), divided and four lanes. The system was installed in 2011 and remains active.

The system monitors wind speed and visibility data from RWIS sites to determine when they have reached specific thresholds. When reduced visibility is detected, the system sends a notification message to an operator, who activates the HARs. When the HARs are activated, the flashing beacon signs are automatically activated. These combined approaches provide warning to drivers. Communications between the HARs and signs is via a.m. radio transmission or DSL/Ethernet, depending on the site.

To date, no formal evaluation of the system has been made. However, an observation of personnel is that there have been issues with false positives generated from the RWIS stations (i.e., notification of low visibility when visibility was fine). There have also been issues with deactivating the flashing beacons when the HAR systems are shut off (i.e., after visibility has improved). In the future, direct communications between the HAR and the signs will be used, likely DSL or similar. Collectively, this type of system would be used again if necessary.

Purpose: Provide drivers with warning of reduced visibility due to dust.

Status: Active

Deployed: 2011

Location: I-10, mp 11-12.

Components: RWIS stations for condition data, controller, Highway Advisory Radios, static warning signs equipped with flashing beacons.

System Contact:
Charles Remkes
Bureau Chief, ITS Office
New Mexico Department of Transportation
Telephone: (505) 222-6554
Email: Charles.remkes@state.nm.us

3.6.6. Conway Summit Automated Wind Warning System (California)

Caltrans District 9 has installed an automated wind warning system along U.S. 395 near Conway Summit (a mountain pass) to address vehicle blow over crashes. The location is a point where terrain concentrates winds, producing crosswinds on the roadway that can blow over vehicles, specifically tractor-trailers and larger recreational vehicles. The site of the wind measurement equipment is postmile 59 along a high speed (65 mph), two lane, undivided highway segment. The system was deployed in mid-2011 and remains active to date.

The system uses equipment to detect wind speed and direction, sending this data to the system field controller. The system processes the data to determine if one of two thresholds has been exceeded. The first threshold is whether a continuous wind speed of 30 mph has been measured for at least three seconds. When this condition is detected, flashing beacons on static metal warning signs are activated and a warning message is sent to DOT staff. The warning signs are located approximately 1 to 1 ½ miles in either direction of the wind detection location. When this threshold has not been met for 30 minutes, the beacons are shut off. The second threshold is for a 40 mph gust over three seconds, which may occur after the system has already been activated. When this threshold is met, the system sends another warning message to staff (the system beacons would already have been activated).

No formal evaluations of the system have been performed to date, although crash data for the period following deployment is now available that will allow for such an evaluation. The challenge with the system and its effectiveness is that there is no alternative route to U.S. 395, so drivers won't generally stop and wait for the winds to pass or detour. It is difficult to anecdotally say whether crashes have been reduced since they were rare events before deployment (1 to 2 per year). However, this type of system has worked well and will be used in another location in the next year (2013-2014). The only change that would be incorporated long term is the inclusion of wind vectors to allow for warnings to be activated for specific travel direction.

Purpose: Provide drivers with warning of high winds.

Status: Active

Deployed: mid-2011

Location: U.S. 395, pm 59.

Components: Wind speed and direction sensors, controller, static warning signs equipped with flashing beacons, solar power.

System Contact:
Phil Graham
Traffic Operations/Electrical
California Department of Transportation, District 9
Telephone: (760) 872-5248
Email: Philip_graham@dot.ca.gov

3.6.7. I-580 Wind Warning System (Nevada)

The Nevada Department of Transportation has been using a wind warning system on I-580 for the past 11+ years between Carson City and Reno. The system, which is deployed between mileposts 44 and 56, targets vehicles over 9 feet in height that are prone to blow over crashes on this roadway segment. The roadway itself is a high speed (65 – 70 mph depending on the segment), divided, four lane section. The system uses dynamic message signs and static warning signs with flashers to provide warning that high winds are present along the corridor.

The system has evolved since its initial deployment. Initially, one RWIS site was used for wind detection, but now additional RWIS sites are being added so that 4 or 5 will be used as part of the system when completed. The data is used by the system controller to trigger different warnings, depending on conditions. For example, the system considers whether the winds are sustained, or just gusts. Warnings are triggered when winds of 40 mph or greater are detected. Originally, one DMS sign was used at either end of the corridor to provide a wind warning message. Now, these DMS signs are supplemented by static warning signs with flashing beacons placed at decision points (e.g., interchanges). Although not part of the system, the Nevada Highway Patrol (NHP) has been diligent about enforcing restrictions during wind events as well.

No formal evaluations of the system have been performed to date, but it has been very effective based on observations and feedback form the NHP. Most truck drivers know this roadway segment is windy, and they tend to comply with the warnings posted by the system. Recreational vehicle compliance has also been acceptable over time. Based on the effectiveness of the system and compliance, a similar system would be used again in the future. In fact, there are two additional locations that experience similar wind issues and NDOT would like to deploy the same system at those sites using the same components. In terms of improvements, NDOT recently (2012) enhanced the system by modifying the detection algorithms. Local calibrations were made for winds though a wind study at each RWIS site. The modifications were made in response to the construction of a high and long bridge along the corridor, which raised concerns related to the winds that would be experienced when crossing it.

Purpose: Provide drivers of high profile vehicles with warning of high winds.

Status: Active

Deployed: 2002

Location: I-580, mp 44 – 56.

Components: RWIS stations, system controller, static warning signs equipped with flashing beacons, DMS.

System Contact:
Tom Moore
Traffic Engineer
Nevada Department of Transportation
Telephone: (775) 888-7566
Email: tmoore@dot.state.nv.us

3.7. Runaway Truck Ramp Warning Systems

Runaway truck ramp systems are used to provide advanced warning that a ramp/arresting bed is in use. The intent of such systems is to prevent secondary crashes from occurring. If the system is activated, trucks that have lost their brakes are warned that they should proceed to the next ramp (if available), because the one being approached is in use.

3.7.1. Arizona Runaway Truck Ramp Warning Systems (Arizona)

Arizona's runaway truck ramp warning systems are located at two sites along SR 68 near Kingman. The specific warning systems were installed in 2008. In some locations, a truck may lose its brakes on a steep downgrade, and the ramp itself (comprised of a gravel bed) acts to stop the truck when driven on. The system uses buried sensors to detect when a runaway truck has entered the ramp. When detected, a DMS sign is activated to inform other truck drivers that the ramp is full and to proceed to the next available location. Cameras are also present at the ramps to allow district and TOC staff to view the ramp. This feature is included to provide visual confirmation of truck presence; in some locations, people stop for picnics on the ramps, which can trigger false detections.

While no formal evaluation has been conducted of the systems, observations indicate that the system works perfectly. Even more systems would be deployed if the funding was available. Based on performance and experience, no changes or improvements to the equipment are needed.

Purpose: Provide warning to truck drivers that the runaway ramp is occupied and to proceed to the next ramp.

Status: Active

Deployed: 2008

Location: Two sites along AZ 68 near Kingman.

Components: Sensors to detect truck presence in ramp bed, closed circuit cameras, system controller, DMS signs.

System Contact:
Reza Karimvand
Assistant State Engineer
Arizona Department of Transportation
Telephone: (602) 712-8328
Email: RKarimvand@azdot.gov

3.7.2. U.S. 16 Runaway Truck Ramp Warning System (Wyoming)

The Wyoming DOT installed a truck ramp warning system to alert drivers that a truck ramp is occupied on a steep downgrade (eastbound) on U.S. 16 east of the town of Buffalo. The system was installed in 2004 along a high speed (55 mph), two lane segment of highway. By providing warning of ramp occupancy, the system's intent is to reduce secondary crashes by other trucks that may also have braking difficulties and need to use the ramp.

The system uses a radar detector to establish vehicle presence on the ramp. When a vehicle is detected, the system controller activates flashing beacons on a static metal sign indicating the ramp is in use. Signage is also used to provide warning of sharp curves ahead and the need to reduce speed. When a vehicle is detected, an automated notification is also sent to the sheriff's office to alert them of the need for response.

While no formal evaluation has been conducted of the systems, observations indicate that the system works well. The only times that fatalities have occurred with a runaway truck have been when the general signs regarding the availability of a ramp ahead were ignored. The system has worked well enough that its use is in the planning stages for two sites along WY 22 in the future. The only change or improvement to the system that would be made is the use of CMS signs to provide more active warning of the ramp being in use. However, this was not possible for the current site because of power and communications limitations.

Purpose: Provide warning to truck drivers that the runaway ramp is occupied.

Status: Active

Deployed: 2004

Location: U.S. 16 eastbound, west of Buffalo, WY.

Components: Radar to detect truck presence in ramp bed, system controller, static metal signs with flashing beacons.

System Contact:
Aaron Huffsmith
ITS Research Engineer
Wyoming Department of Transportation
Telephone: (307) 777-4232
Email: aaron.huffsmith@dot.state.wy.us

3.7.3. I-5 Truck Escape Ramp Warning System (California)

Caltrans installed a truck ramp warning system to alert drivers that one of two truck ramps are occupied on a downgrade on I-5 south of Bakersfield. The system was installed in 2005 along a high speed (70 mph) four lane segment of divided highway between postmiles 8.23 and 8.24. The system actually arose out of a need to inventory how many trucks were using the ramp, as the site was sometimes being used by passenger vehicles as a pull off and picnic area.

The system uses an inductive loop detector to sense when a vehicle has entered a ramp. When a vehicle is detected, the system controller sends district staff a text message and email, triggers a CCTV camera for monitoring and activates an EMS sign indicating the ramp is in use. The CCTV camera is set to record video for 5 seconds prior to a vehicle entering the ramp and continues recording for two minutes after ramp entry.

While no formal evaluation has been conducted of the systems, experience has shown the system has been effective. It has provided district staff with good information on how often the ramps are being used, and has also assisted in better timing of maintenance forces being dispatched to the site to restore the gravel arresting pits when necessary. As a result, a similar system would be used again if needed.

The system has been upgraded over time, including changes to the wiring of the EMS signs, changes to communications at the site, and the addition of CCTV cameras. Most of the general system components would be used again, although an update to the system controller is planned to allow for TMC operators to log in and reset the EMS signs, which is done manually by California Highway Patrol or maintenance staff at present.

Purpose: Provide warning to truck drivers that the runaway ramp is occupied.

Status: Active

Deployed: 2005

Location: I-5, pm 8.23 and 8.24.

Components: Inductive loops to detect truck presence in ramp bed, system controller, EMS signs, CCTV.

System Contact:
Jose De Alba
District 6
California Department of Transportation
Telephone: (559) 445-6709 ext. 239
Email: jose_dealba@dot.ca.gov

3.8. Flood Warning Systems

Flood warning systems are used to warn drivers that a roadway or bridge is flooded. The intent is to stop drivers from continuing on and encountering flood waters, potentially being stranded or encountering harm. These systems have been in use for years to address potential flooding situations ranging from tsunamis to swollen creeks.

3.8.1. Cushman Flood Warning System (Oregon)

The Cushman flood warning system is located near Florence, Oregon, on SR 126 between mileposts 2.9 and 3.1. Activated in 2006, it is intended to warn drivers about water/flooding on the roadway. The system is located along an undivided, high speed (50 mph) section of road and uses float sensors to detect water present on the roadway. When water is detected, flashers are turned on at two warning sign locations at either end of the road segment.

While no formal evaluation has been conducted of the system, observations indicate that the system works adequately. However, the float sensors are problematic and produce false positives (i.e., detect water when none is present) on occasion. However, the system has automated a process that was previously conducted manually, which has resulted in labor savings. While such a system would be deployed elsewhere if needed, the float sensors would be replaced by a different, more reliable sensing technology.

Purpose: Warn motorists of water/flooding at a low point on the roadway.

Status: Active

Deployed: 2006

Location: SR 126 between mp 2.9 – 3.1.

Components: Float sensors, system controller, static warning signs with flashing beacons.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

3.8.2. Seaside Flood Warning System (Oregon)

The Seaside flood warning system is located near Seaside, Oregon, on U.S. 101 between mileposts 22.66 and 23.54. Activated in 2006, it is intended to warn drivers about water/flooding on the roadway in a low lying area. The system is located along an undivided, low speed (45 mph) section of road and uses ultrasonic level sensors to detect water presence on the roadway. When water is detected, flashers are turned on at two warning sign locations at either end of the road segment.

While no formal evaluation has been conducted of the system, observations indicate that the system works well. The ultrasonic sensors work better than float-type sensors for water level detection. The system has automated a process that was previously conducted manually, which has resulted in labor savings. A similar system would be deployed elsewhere if needed, using the same components deployed at Seaside.

Purpose: Warn motorists of water/flooding at a low point on the roadway.

Status: Active

Deployed: 2006

Location: U.S. 101 between mp 22.66 – 23.54.

Components: Ultrasonic level sensors, system controller, static warning signs with flashing beacons.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

3.8.3. Tillamook Flood Warning System (Oregon)

The Tillamook flood warning system was deployed by the Oregon Department of Transportation to monitor potential flooding conditions near the Wilson River bridge on U.S. 101. The system was deployed in 2000, and remained active for approximately nine years. It is now inactive after being removed approximately four years ago. While active, the system was located on a two lane, undivided, low speed (45 mph) road.

While active, the system used an ultrasonic sensor unit to monitor river levels. When a predetermined threshold was met, the system sent a signal to a data acquisition autodialer, which called the local maintenance manager for notification purposes. Once notified, the maintenance manager took the necessary steps to address the potential flooding issue (ex. bridge closure). Note that the system did not activate any warning devices in the field, such as static signs with flashing beacons.

During the course of its deployment, no formal evaluations were conducted of the system. Similarly, no observations were made regarding the effectiveness of the system in meeting its intended purpose. However, based on their performance, the ultrasonic sensors would be used as part of a similar system in the future, should the need arise in another location. However, the autodialer component would not be used again. Instead, the Advanced Transportation Controller (ATC) system would be used in its place as the system controller.

Purpose: Provide maintenance manager with warnings of potential flooding conditions.

Status: Inactive

Deployed: 2000

Location: U.S. 101 Willson River bridge, in Tillamook, OR.

Components: Ultrasonic level sensors, autodialer.

System Contact:
Doug Spencer, P.E.
ITS Standards Engineer
Oregon Department of Transportation
Telephone: (541) 747-1276
Email: doug.l.spencer@dot.state.or.us

3.8.4. Sonoma Creek Flood Warning System (California)

The Sonoma Creek flood warning system is located on State Route 121 at postmile 7.3. Activated in 2003, it is intended to warn drivers about water/flooding at the bridge site that can result from restrictions in the path of the creek, allowing water to back up. The system is located along an undivided, high speed (50 mph) section of two lane road and uses a radar sensor mounted on the bridge to detect rising water. When a certain level of water is detected, the system controller triggers flashers at two warning sign locations at either end of the road segment.

While no formal evaluation has been conducted of the system, observations over time indicate that the system works well. The radar sensors replaced earlier float sensors that had been problematic in effectively detecting rising water at the particular site. The radar sensors have been found to work better than the earlier float-type sensors. If a similar need arose at another creek crossing location, the same system would be used again.

Purpose: Warn motorists of creek flooding at Sonoma Creek bridge site.

Status: Active

Deployed: 2003

Location: SR 121, pm 7.3.

Components: Radar level sensors, system controller, static warning signs with flashing beacons.

System Contact:
Charles Price
Office Chief, District 4
California Department of Transportation
Telephone: (510) 286-4478
Email: Charles.price@dot.ca.gov

3.9. Visibility Warning Systems

Visibility warning systems have been employed in various locations to provide warning to drivers during fog and dust conditions. The exact aim of each system varies, from providing warning of reduced visibility and slowed traffic ahead to providing warning of an approaching signalized intersection obscured by reduced visibility. The systems identified during this work are deployed to address site-specific problems, but in general function in the same manner.

3.9.1. I-15 Dust Warning System (Montana)

To address a localized dust issue along I-15, the Montana DOT installed a visibility warning system in August of 2013. When a lake bed adjacent to the interstate is dry, alkali dust blows across the interstate, which has led to visibility problems and a number of crashes, including one with a fatality. As a result, the dust warning system was installed to provide drivers traveling in each direction with warning along a one mile segment of roadway. The system is located along a divided, high speed (75 mph) segment of four lane interstate at milepost 389. It remains active to date.

The system is straightforward in terms of components. Visibility sensors located at the midpoint of a one mile section of roadway adjacent to the lake monitor visibility conditions. When the lake bed is dry and wind raises dust, the visibility sensors provide that data to the system controller, which activates flashing beacons on static metal signs at each end of the one mile segment. The system is solar powered.

Due to the recent deployment of the system, no formal evaluations have been completed to date. Additionally, the lake has not been dry recently, and as a result, there have been no dust storms to trigger the system to provide warning. However, it is expected that the system will work as intended in the future when the lake becomes dry once again and advance warning will be provided to drivers.

Based on the development of the system itself, it would be used in other locations in the state if a similar need arose. Given the straightforward components of the system, no changes or improvements have been identified to date. However, it was discovered that, as the days grew shorter at the site, the solar panels were not adequate to meet system needs. Additional panels are being installed to address the issue.

Purpose: Provide drivers with warning of reduced visibility.

Status: Active

Deployed: 2013

Location: I-15, mp 389.

Components: Visibility sensors, system controller, flashing beacons on static metal signs.

System Contact:
Steve Keller
Communications Bureau Chief
Montana Department of Transportation
Telephone: (406) 444-6305
Email: stkeller@mt.gov

3.9.2. District 10 Visibility Warning System (California)

Caltrans District 10 installed visibility warning systems along I-5 and SR 120 in order to address low visibility crashes and provide warning of highway congestion in the Stockton and Manteca area. The systems, activated in November 1996, are located between postmiles 15.9 and 21.96 on I-5 and postmiles 0.60 and 6.07 on SR 120. Both routes are high speed (55 mph+), divided, multilane roads.

The systems use meteorological stations to detect visibility conditions and speed detectors to determine traffic conditions, with warnings provided to motorists via CMS signs at various points. When low visibility and/or congested conditions reach given thresholds based on data evaluated by the system controller, the CMS signs on the respective road are activated with specific warning messages. These include "Slow Traffic Ahead" (for detected speeds less than 35 mph), "Stopped Traffic Ahead" (for detected speeds less than 11 mph), "High Wind Warning" (when wind speeds above 25 mph detected), "Foggy Conditions Ahead" (when visibility is between 200 and 500 feet) and "Dense Fog Ahead" (when visibility is less than 200 feet).

While no conclusive results from an evaluation of the system are known to have been published, an initial discussion of different aspects of the system was published in 1999. This discussion provided initial trends related to crashes, which did not show any conclusive changes based on the presence of the system. The system itself might be used again if a specific site had a similar visibility issue. The same components would be used overall, although Caltrans would conduct a review of newer components that have become available over time before any new system was developed and deployed.

Purpose: Provide warning of low visibility and presence of highway congestion.

Status: Active

Deployed: November 1996

Location: I-5, pm 15.9, 17.04, 18.81, 20.22 and 21.96; SR 120, pm 0.60, 2.76, 4.79 and 6.07.

Components: Meteorological stations, traffic speed detectors, system controllers and CMS.

System Contact:
John Castro
District 10
California Department of Transportation
Telephone: (209) 948-7449
Email: john_castro@dot.ca.gov

Evaluation - Evaluation of Caltrans District 10 Automated Warning System: Year Two Progress Report http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1295&context=eeng_fac

3.9.3. I-215 Low Visibility Warning System (Utah)

The Utah DOT deployed a low visibility warning system along I-215 in the Salt Lake City area during the winter of 1999/2000. The system was aimed at providing warning to motorists in a low lying river area of fog caused by a local inversion. The site was a high speed (65 mph), divided, multilane interstate. Due to issues with instruments and their placement, the system was removed during 2003.

When deployed, the system used four forward-scatter visibility sensors and six vehicle detection sensors to collect data on current visibility and traffic conditions. This data was used by a central controller to determine if visibility had deteriorated and if so, what warning should be posted on two roadside DMS signs based on traffic conditions. When conditions warranted, the following messages were provided:

- Visibility 656 ft. – 820 ft: “Fog Ahead”
- Visibility 492 ft. – 656 ft: “Dense Fog Advise 50 mph”
- Visibility 328 ft. – 492 ft: “Dense Fog Advise 40 mph”
- Visibility 197 ft. – 328 ft: “Dense Fog Advise 30 mph”
- Visibility less than 197 ft: “Dense Fog Advise 25 mph”

An evaluation of the system found that overly cautious drivers (those already driving below the posted speed limit) increased their speeds when the system was active, with average speeds increasing 15 percent (from 54 to 62 mph). Speed variance decreased by 22 percent (from 9.5 to 7.4 mph), which enhanced mobility and reduced the risk of initial and secondary crashes.

Although the results discussed in the evaluation were encouraging, the system itself was not reliable and ultimately removed in 2003. At the time, the instrumentation necessary for visibility detection was poor, and there was a need for better placement of the instruments themselves. This resulted in too many false positives of fog detection occurring, with the system turning on when it was not necessary. Since the system was entirely automated in the field and didn’t rely on TMC input or activation, there was a greater need for system algorithms to incorporate a margin of safety, but this was not done. Since the time the system was removed, the quality and effectiveness of visibility sensors has improved, so it is possible that a system using these newer sensors might be considered in another location. In addition, any future system needs to use multiple sensors to determine conditions across a given length of roadway.

Purpose: Provide warning of low visibility due to inversions in a low lying area.

Status: Inactive (removed 2003)

Deployed: Winter 1999/2000

Location: I-215, mp 10 – 15.

Components: Forward-scatter visibility sensors, vehicle detection sensors, system controller, DMS signs.

System Contact:
Ralph Patterson
Narwhal Group
Telephone: (801) 518-2442
Email: ralph@narwhalgroup.com

Evaluation: http://utah.ptfs.com/awweb/awarchive?item=12705

3.9.4. District 6 Fog Detection and Warning System (California)

Caltrans District 6 deployed a fog detection and warning system along a 12 mile stretch of SR 99 in 2009. The system is located between postmiles 10.5 and 52.24 (note that the route crosses a county line, resulting in discrepancy in postmile distance). The route is a divided, high speed highway (65+ mph), with four lanes cross section. The system remains active to date.

The system uses six weather stations, 22 visibility sensors, 12 CCTV cameras and 41 microwave vehicle detection sensors to detect current conditions on the route. Data from these elements is processed by field controllers that communicate with one another by point to point and point to multipoint radio. If the system detects deteriorated visibility downstream, motorists are provided with warnings via 33 CMS signs (and 6 portable CMS as needed). In addition to deteriorated visibility, the system is also used to provide warning of slower traffic ahead.

No formal evaluation of the system has been made, but there have been no major incidents or crashes on the route related to visibility since deployment. It needs to be noted that such events happened previously every 5 to 10 years, so the true effectiveness of the system won't be evident for some time. The system is fairly complex and equipment intensive, so its use elsewhere might be more limited to other locations with severe visibility concerns. Given the recentness of the deployment, it is not clear if any different components might be changed for future systems. However, it may be useful to add incident detection capability in the system in the future.

Purpose: Provide warning of low visibility and presence of highway congestion.

Status: Active

Deployed: 2009

Location: SR 99, pm 10.5 to 52.24.

Components: Weather stations, visibility sensors, CCTV, microwave vehicle speed detectors, system controllers and CMS.

System Contact:
Jose DeAlba
District 6
California Department of Transportation
Telephone: (559) 445-6709 ext. 239
Email: jose_dealba@dot.ca.gov

3.9.5. SR 18 Visibility Warning System (California)

Caltrans District 8 deployed a visibility warning system on SR 18 at the intersection with Lake Gregory Drive in 2010. The purpose of the system is to provide advanced warning of an upcoming signalized intersection ahead that cannot be seen by drivers during foggy conditions. The system is located along a low speed (45 mph) section of undivided section of two lane highway.

The system uses a visibility sensor to detect foggy conditions. When fog is present, the system controller activates DMS signs in each direction of travel. The message provided to drivers is basic, warning of a signal located ahead. Given the relatively recent date of deployment, no formal evaluation of the system has been made. However, when the signal was initially installed, the District received a number of complaints which have since stopped, which may be related in part to the warning system.

Based on the simple design and components of the system, a similar system was deployed again in another location (SR 138 at its intersection with SR 2). Based on the SR 18 system success, no component changes were made to the follow-up deployment, nor are any expected in the future if additional deployments are made. However, the message displayed to drivers might incorporate a flashing mechanism when the signal ahead is red to further draw the attention of drivers. In addition, a different message to drivers might also be considered.

Purpose: Provide warning during low visibility of a signalized intersection ahead.

Status: Active

Deployed: 2013

Location: SR 18 at its intersection with Lake Gregory Drive.

Components: Visibility sensor, system controller and DMS signs.

System Contact:
Thomas Ainsworth
Chief, Traffic Management Systems Support
District 8
California Department of Transportation
Telephone: (909) 356-3755
Email: Thomas_ainsworth@dot.ca.gov

3.9.6. SR 138 Visibility Warning System (California)

Caltrans District 8 deployed a second visibility warning system on SR 138 at the intersection with SR 2 in 2013. The purpose of the system is to provide advanced warning of an upcoming signalized intersection that cannot be seen by drivers during foggy conditions. The system is located along a high speed (55 mph) section of undivided section of four lane highway.

The system uses a visibility sensor to detect foggy conditions. When fog is present, the system controller activates DMS signs in each direction of travel. The message provided to drivers is basic, warning of a signal located ahead. Given the recent date of deployment, no formal evaluation of the system has been made.

Based on the simple design and components of the system, a similar system would be deployed again in another location if needed. This system was itself a follow-up based on an initial installation made at the intersection of SR 18 and Lake Gregory Drive in another location in the District. No component changes are anticipated for any future deployments. However, the message displayed to drivers might incorporate a flashing mechanism when the signal ahead is red to further draw the attention of drivers.

Purpose: Provide warning during low visibility of a signalized intersection ahead.

Status: Active

Deployed: 2010

Location: SR 138 at its intersection with SR 2.

Components: Visibility sensor, system controller and DMS signs.

System Contact:
Thomas Ainsworth
Chief, Traffic Management Systems Support
District 8
California Department of Transportation
Telephone: (909) 356-3755
Email: Thomas_ainsworth@dot.ca.gov

3.10. Additional Systems

This section discusses additional types of safety warning systems that are unique and do not fit into the general categories of systems discussed in the previous sections of this document. These systems address a wide range of issues, including overlength and height vehicle conflicts, earthquake closures for elevated structures, travel time systems (when indicated as being automated), speed warnings for heavy vehicles on downgrades, avalanche warning and tunnel fire warning. These systems use a diverse set of approaches to detect conditions and provide warning. In some cases, the system only provides notification to DOT maintenance staff, while in other cases, the roadway itself is closed to users.

3.10.1. U.S. 395 Over Length Detection System (Oregon)

The U.S. 395 over length detection system was activated in 2012 to warn drivers that an over length vehicle is present in the corridor. It was deployed to address incidents involving over length vehicles traveling to a lumber mill within the corridor. The system is located along an undivided, high speed (55 mph) section of two lane road. When an over length vehicle is detected, beacons on a static warning sign are activated at each end of the corridor to provide warning that an over length vehicle is present.

The system uses a Wavetronix unit to detect vehicle length, with this data sent to a 2070 controller. The controller is connected to static metal signs equipped with flashing beacons, and these beacons are activated when an over length vehicle is detected. Note that no minimum length of vehicle has been specified; however, all tractor trailers activate the system. The signs are located at both ends of the corridor to provide warning to drivers in both directions of travel.

No evaluation of the system has been performed to date, primarily because of its more recent deployment. However, based on its design, the system concept would be used elsewhere if the need existed. Some different components would be used however, specifically, the new Advanced Transportation Controller.

Purpose: Provide warning that an over length vehicle is present within the corridor.

Status: Active

Deployed: 2012

Location: U.S. 395, mp 50 – 60.

Components: Wavetronix length detection unit, controller, static metal signs with flashing beacons.

System Contact:
Doug Spencer, P.E.
ITS Standards Engineer
Oregon Department of Transportation
Telephone: (541) 747-1276
Email: doug.l.spencer@dot.state.or.us

3.10.2. McKenzie Over Length Detection System (Oregon)

The McKenzie over length detection system is located east of Eugene, Oregon, on SR 242 between mileposts 61.0 and 84.0. Activated in 2004, it is intended to warn drivers of vehicles whose length exceeds 35 feet that their vehicle exceeds the length threshold for that segment of highway. It was deployed to address crashes and incidents involving over length vehicles on the segment, which had resulted in corridor closures. The system is located along an undivided, low speed (<45 mph) section of road. When an over length vehicle is detected, beacons on a static warning sign are activated to warn the driver not to proceed.

The system works by using inductive loop speed traps to detect vehicle speed and occupancy. This information is sent to the system controller, which compares it to established thresholds to determine if the vehicle exceeds them. When an over length vehicle is detected, the system activates flashing beacons on a static sign to provide warning to the driver. A second system located beyond the turnaround points for either end of the corridor performs the same operation and sends an email notification to the Transportation Operations Center if the vehicle continues on beyond that point.

An informal examination of data from the system in 2004 showed that 54 of 75 over length vehicles that were detected did not proceed into the corridor (reaching the second measurement points). While the system is designed to address a unique situation, its performance over time has led to the conclusion that it would be used at other sites should the need arise. The only change that might be considered is the use of newer sensing technologies in the place of the inductive loops presently used.

Purpose: Warn vehicles exceeding 35 feet not to continue through the corridor.

Status: Active

Deployed: 2004

Location: SR 242; mp 61.0 – 84.0.

Components: Inductive loops to detect vehicle occupancy and speed, central controller, static warning signs with flashing beacons.

System Contact:
Galen McGill P.E.
ITS Program Manager
Oregon Department of Transportation
Telephone: (530) 986-4486
Email: galen.e.mcgill@dot.state.or.us

3.10.3. Alaskan Way Viaduct Earthquake Warning System (Seattle)

The Alaskan Way Viaduct earthquake warning system in downtown Seattle functions to provide closure of the two deck freeway to ensure driver safety. The viaduct structure is old (it is currently being replaced by a tunnel) and inspections raised concerns that it could fail during an earthquake, particularly following a 2001 seismic event. The road itself is a multideck, high speed freeway. The closure system was installed in mid-2011.

The system is composed of seismic detectors, system controllers and closure gates. When an earthquake of 5.0 or greater on the Richter scale is detected, the system closes gates on the mainline prior to the structure and at its entrance ramps to prevent vehicles from using the viaduct until it is inspected. Since its installation, the system has only been triggered once by an event, although it is also tested monthly.

While no evaluations of the system have been made to date, WSDOT has found it to be satisfactory and would consider using it in other locations should the need arise. The components used are basic, and no improvements or changes to them have been identified since deployment.

Purpose: Close the Alaskan Way Viaduct in downtown Seattle when seismic activity is detected.

Status: Active

Deployed: 2011

Location: The Alaskan Way Viaduct in downtown Seattle.

Components: Seismic sensors, system controllers, road closure gates.

System Contact:
Bill Legg
State ITS Operations Engineer
Washington State Department of Transportation
Telephone: (360) 705-7994
Email: leggb@wsdot.wa.gov

3.10.4. King County Travel Time System (Washington)

The travel time system in King County, Washington, is designed to detect travel times and congestion, allowing for this information to be disseminated to motorists via changeable message signs. The system was expected to be activated during 2013. It is located along the Avondale Road Northeast corridor between Northeast 128th Way and Northeast Union Hill Road in Redmond, Washington. The roadway is low speed (generally 35-40 mph), between two and four lanes (depending on location), and undivided. The route is a highly trafficked corridor and prone to congestion. However, there are alternative routes available, and by providing drivers with travel time and congestion information via roadside signage, drivers will be able to select an alternative route at key decision points.

The system uses three license plate readers positioned at key intersections along the corridor, as well as three Wavetronix microwave vehicle detection sensors that collect travel time and speed measurements along the route. This data is provided to a central computer at the TMC for processing, with the system providing travel time messages to changeable message signs along the route (southbound direction of travel only). These messages consist of the following: "Travel time from NE 128th to Union Hill XX min" or "Travel time from Novelty Hill to Union Hill XX min." These messages are posted in advance of decision points so a driver can take an alternative route if congestion is occurring.

As the system has not yet been activated, no evaluations of its performance have been made. However, during development of the system, it has been debated whether the system will be too cumbersome in terms of the technologies being used. In the future, alternative technologies for establishing travel time, such as Bluetooth, may be examined. Also, travel times in the northbound direction may be added.

Purpose: Provide information to motorists regarding current travel times and potential congestion on a high traffic corridor.

Status: Presently being installed

Deployed: 2013

Location: Avondale Road Northeast between Northeast 128th Way and Northeast Union Hill Road in Redmond, Washington.

Components: Three license plate readers located at key intersections, three Wavetronix microwave vehicle detection sensors for speed measurement, a central control computer, and two changeable message signs in southbound travel direction.

System Contact:
Aileen McManus
ITS Project Manager
King County (Washington) Roads Division
Telephone: (206) 263-6135
Email: aileen.mcmanus@kingcounty.gov

3.10.5. Phoenix Travel Time System (Arizona)

The Phoenix area travel time system is deployed throughout the valley area along I-10, I-17, and on the SR 51, SR 101 and SR 202 loops. The system provides drivers with an estimated travel time to different destinations so that they can make decisions regarding detours or alternate routes in advance of decision points. The system covers 400 directional miles, and provides travel times for 60 different destinations (depending on location). The system was deployed in 2008 and remains active.

The system is comprised of loop detectors (providing 90 percent of the data), 3rd party data (10 percent of data) to collect speed data, central computers and dynamic message signs. The system uses the loop detector and 3rd party data to estimate travel times based on prevailing speeds, which are then posted to the DMS signs throughout the network. The system is entirely automated, although a TOC operator can extend the length of time that travel times are displayed by the DMS.

No formal post deployment evaluation has been conducted of the system; however, observations by ADOT staff indicate that it has been very effective and the traveling public likes the information provided. The system would be deployed (or expanded) elsewhere if funding was available, and the same components would generally be used. However, there is a desire to move entirely to loop detectors for data collection. This is the result of the 3rd party data provider not identifying the resources that they are using to obtain their data. The result is that ADOT staff members do not have 100 percent confidence in the data as they do with loop detectors. Additionally, an alternate route system is being developed to provide additional information to travelers while they are en route.

Purpose: Provide drivers with estimated travel times to various destinations in the Phoenix valley area.

Status: Active

Deployed: 2008

Location: Metropolitan Phoenix, Arizona.

Components: Loop detectors and 3rd party data to establish travel speeds, central processing computer, dynamic message signs.

System Contact:
Reza Karimvand
Assistant State Engineer
Arizona Department of Transportation
Telephone: (602) 712-8328
Email: RKarimvand@azdot.gov

3.10.6. Denver Area Travel Time System (Colorado)

Colorado's travel time systems along interstates in the Denver Area are designed to provide real time traveler information to facilitate the selection of alternative routes by drivers during incidents, congestion, etc. The systems are deployed on I-25 between Colorado Springs and Denver, and on I-70 between Vail and the Denver International Airport. Traffic detectors (Doppler radar) along each route, as well as toll tag readers, provide the data that is used by a central computer to establish travel times. These travel times between different points on each route are posted to Variable Message Signs.

While no formal evaluations have been conducted, CDOT staff members indicate that the system is about 80 percent accurate in terms of estimating prevailing travel times. This has been confirmed through internal testing and data analysis. Additionally, the system has been well received by the public. The system keeps being expanded, and improvements have also been made to the existing sites, such as improved detector device placement. The cost of detector equipment is becoming more expensive however, and CDOT may consider purchasing 3rd party data to address this in the future.

Purpose: Provide drivers with estimated travel times on Interstate routes in the Denver area.

Status: Active

Deployed: 2005

Location: I-25 (Colorado Springs to Denver); I-70 (Vail to Denver International Airport).

Components: Traffic detectors (Doppler radar), toll tag readers, central processing computer, variable message signs.

System Contact:
Jill Scott, P.E.
Resident Engineer in ITS
Colorado Department of Transportation
Telephone: (303) 512-5805
Email: jill.scott@state.co.us

3.10.7. Harrisburg Bridge Over-Height Vehicle Warning System (Oregon)

The Oregon Department of Transportation deployed an over-height vehicle detection and warning system on State Route 99 East near the town of Harrisburg in December, 2001. This is a bridge site that had experienced over-height vehicle strikes that had damaged the structure and necessitated lengthy (45 minute) detours via an alternative route. The system is located approximately at milepost 29.2 and was set up to detect over-height vehicles approaching the bridge in either direction. The roadway at the site is low speed (45 mph), undivided and two lanes. The system remains active as of 2013.

The system is comprised of a bidirectional infrared light beam transmitter and receiver that determine vehicle height by direction of travel. When a vehicle exceeding a safe height (greater than 14 feet 11 inches) is detected, flashing beacons on a static metal warning sign are activated by the system controller for the specific direction that the vehicle is travelling (i.e., only one sign would flash rather than each sign in both directions). Supplemental guide signage is also provided to direct the vehicle along an alternative route with adequate clearance.

No formal evaluation of the system has been made, but there has not been a bridge strike by an over-height vehicle since the system was installed in 2001. A similar system would be used again in the future if the need arose elsewhere on the state highway system. However, any new system would use different components, specifically lasers rather than infrared beams. The choice of laser does not reflect on the performance of the infrared system but rather, the evolution of detection technologies in the decade plus since the Harrisburg system was deployed.

Purpose: Automate detection of over-height vehicles to trigger warning signs.

Status: Active

Deployed: December, 2001

Location: State Route 99E in Harrisburg, OR.

Components: Bi-directional infrared transmitter and receivers, system controller, flashing beacons on static warning signs, additional static warning signs to mark alternative route.

System Contact:
David Fifer
ITS Specialist – Motor Carrier Division
Oregon Department of Transportation
Telephone: (503) 378-6054
Email: david.a.fifer@odot.state.or.us

3.10.8. I-25 Overheight Vehicle Detection System (Wyoming)

The Wyoming DOT deployed an overheight vehicle detection system in 2009 in the Casper area to address vehicle strikes on a low bridge. The low bridge is actually located on I-80, but the system warns overheight vehicles traveling on I-25 that they are too high and must take an alternative detour route before reaching the low bridge. This is accomplished by providing a message to any detected overheight truck passing the system location before it reaches the I-80 interchange. The system is deployed on I-25 between mileposts 184.00 and 184.85. At this point, the interstate is a divided, four lane route with a 75 mph speed limit. The system remains active to date.

The system uses two separate sets of overheight sensors mounted to overhead cantilevers (one on the median, one on the shoulder). When an overheight vehicle is detected, the system controller triggers a warning message on an EMS sign stating "Overheight, Exit Right."

No formal evaluation of the system has been performed to date. Observations by WYDOT staff indicate that since the system was deployed, there have been no vehicle strikes on the low bridge. Based on this performance to date, a similar system would be considered in the future if the need arose elsewhere. The same components would be used overall, although there has been discussion of the need to add a logging system to track and/or count the number of times a warning message is triggered. In addition, the installation of a vehicle counter in conjunction with the system might be useful. Finally, providing a record of the system being triggered to the local Port of Entry would be helpful with aspects of motor carrier management.

Purpose: Provide trucks with an overheight warning before reaching I-80 from I-25.

Status: Active

Deployed: 2009

Location: I-25, mp 184.0 – 184.85.

Components: Overheight detectors, system controller, EMS sign.

System Contact:
Aaron Huffsmith
ITS Research Engineer
Wyoming Department of Transportation
Telephone: (307) 777-4232
Email: aaron.huffsmith@dot.state.wy.us

3.10.9. Downhill Speed Information System (Oregon)

The Oregon Department of Transportation installed a downhill speed information system along I-84 in December, 2002. The purpose of the system was to provide warning to truck drivers to slow down for a six percent downgrade on Emigrant Hill. This was a site that had experienced several truck crashes including fatalities. Using a transponder reader and data from a previous weigh in motion scale, a message is posted to a changeable message sign providing a recommended speed for the vehicle based on its measured weight. The site of the downhill warning equipment is milepost 227.4 (westbound direction) along a high speed (55 mph), four lane divided highway segment. The system remains active to date.

The system uses a transponder reader to detect a truck and uses data collected from a weigh-in-motion scale site upstream to determine a recommended speed based on its weight. The recommended speed is then posted to a CMS sign. Trucks that have weights below 60,000 pounds and over 80,000 pounds are only provided with a message warning “Steep Downgrade.” All messages posted to the sign include the trucking company or owner’s name. Note that since the system relies on transponder readings, only trucks equipped with a transponder can be provided with warnings at the present time.

No formal evaluations of the system have been performed to date, although there has been a noticeable reduction in reportable truck crashes. The system would definitely be used again in another location if the need arose. However, newer variable message signs would be incorporated, and license plate readers might be considered in place or in conjunction with the transponder reader equipment. This would allow for truck-specific messages to be provided to all vehicles. The use of license plate readers would be contingent on improvements to that technology, however. Alternatively, a single load cell scale could also be used in conjunction with an Automated Vehicle Identification (AVI) reader to similarly produce vehicle-specific messages.

Purpose: Provide trucks with warnings for a steep downgrade.

Status: Active

Deployed: December 2002

Location: I-84, mp 227.4 (westbound).

Components: Transponder reader, system controller, access to upstream weigh in motion data, CMS sign.

System Contact:
David Fifer
ITS Specialist – Motor Carrier Division
Oregon Department of Transportation
Telephone: (503) 378-6054
Email: david.a.fifer@odot.state.or.us

3.10.10. I-70 Dynamic Downhill Truck Speed Warning System (Colorado)

To address downhill speeds on a 5 to 7 percent grade on I-70, the Colorado DOT deployed a dynamic downhill truck speed warning system in May of 1998. The purpose of the system is to address runaway truck crashes, which had occurred with some frequency prior to the system being deployed. This is accomplished by providing a vehicle-specific safe operating speed for each truck passing the system location. The system is deployed approximately 0.2 miles west of the Eisenhower tunnels, at the start of the 10 mile downgrade for westbound traffic. This system is located along a low speed (30 mph for trucks) segment of divided, four lane interstate. The system remains active to date.

The system uses inductive loops and Piezo weigh-in-motion sensors to detect trucks, their speed, weight, axle count and axle spacing. This information is sent to the system controller, which uses the data to determine an appropriate speed (advisory) for the truck. This calculated speed is then posted to a VMS sign located on a gantry above both westbound lanes.

An evaluation of the system was made following deployment and published in 1999. That evaluation found that truck drivers had positive views of the system and believed it improved safety when surveyed. An evaluation of speed data found that when the system was operating, truck speeds were 7.6 mph lower than when the system was not operating. To date, a follow-up study of the long-term effectiveness of the system has not been made.

The system itself would be used again, and other prospective locations had been identified in the past, although they have not been built. The same components would be used overall, although frequent maintenance of the system is necessary for it to operate reliably. This includes frequent calibration of the sensors.

Purpose: Provide trucks with a recommended advisory speed for a steep downgrade.

Status: Active

Deployed: 1998

Location: I-70, at the exit of the Eisenhower tunnel (westbound).

Components: Inductive loops, Piezo sensors, system controller, VMS sign.

System Contact:
Michael Salamon
Tunnel Superintendent
Colorado Department of Transportation
Telephone: (301) 512-5730
Email: Michael.salamon@dot.state.co.us

Evaluation: Janson, Bruce. *Evaluation of the Downhill Truck Speed Warning System on I-70 West of Eisenhower Tunnel*. University of Colorado, Denver, December 1999.

3.10.11. Little Cottonwood Canyon Avalanche Detection System (Utah)

The Utah DOT deployed an avalanche detection system along Hwy 210, a low speed (40 mph), two lane undivided route through Little Cottonwood Canyon. It was installed in 2007 and became fully functional in 2009 and is used to provide DOT staff with an alert (cell phone call) that an avalanche has potentially occurred. This information is used by maintenance forces to carry out an inspection in the area and close the road if necessary. The system does not directly provide motorists with warning of an avalanche or close the road, and there are no plans to use it to do so.

The system uses infrasonic arrays (multiple sensors per array) to detect ultralow frequency noise in near real time. That data is sent back to a central computer which evaluates it and determines if an avalanche has potentially occurred at 90 second intervals. If a potential avalanche has been detected, DOT staff members are alerted via an automated cellular phone call. Since deployment, the system has been effective in its forecasting and staff warning capacities. It has also been useful in producing visualizations of the slide paths created during avalanche control activities, providing verification that efforts were effective. Based on this performance, use of similar systems elsewhere would be considered. No changes to the system components are recommended. The exact number of arrays needed depends on the number of avalanche paths present at a site.

Purpose: Provide DOT personnel with notification of potential avalanche.

Status: Active

Deployed: 2007

Location: Hwy 210, midsection of Little Cottonwood Canyon.

Components: Infrasonic sensor arrays, central computer for data processing.

System Contact:
Liam Fitzgerald
Highway Avalanche Safety Program Supervisor
Utah Department of Transportation
Telephone: (801) 742-2927
Email: lfitzgerald@utah.gov

Evaluation: http://www.udot.utah.gov/main/uconowner.gf?n=7747228490333964

3.10.12. Highway 189 Avalanche Detection System (Wyoming)

The Wyoming DOT deployed an avalanche detection system along Hwy 189 on Teton Pass, a low speed (<45 mph), two lane undivided route. It was installed between 2003 and 2004 and is used to provide DOT staff with an alert (text message) that an avalanche has potentially occurred. This information is used by maintenance forces to carry out an inspection in the area and implement the proper action (i.e., road closure) as needed. While the system does not directly provide motorists with warning of an avalanche or close the road, it does have that potential in the future.

The system uses infrasonic arrays (six or more sensors per array) to detect ultralow frequency noise in near real time. That data is sent back to a central computer which evaluates it and determines if an avalanche has occurred. A text message is then sent to staff if an avalanche has potentially been detected. Since deployment, the system has been effective but does have false alarms generated at times. Based on this performance, use of similar systems elsewhere is highly recommended. No changes to the system components are recommended, but multiple sensor arrays should be used to provide the most accurate results. The exact number of arrays needed depends on the number of avalanche paths present at a site.

Purpose: Provide avalanche detection and DOT personnel notification.

Status: Active

Deployed: 2003-2004

Location: Hwy 189 on Teton Pass.

Components: Infrasonic sensor arrays, central computer for data processing.

System Contact:
Jamie Yount
Avalanche Technician
Wyoming Department of Transportation
Telephone: (307) 732-9622
Email: Jamie.yount@dot.state.wy.us

Evaluation: Yount, Jamie, Adam Naisbitt, and Ernie Scott. *Operational Highway Avalanche Forecasting Using the Infrasonic Avalanche Detection System*. International Snow Science Workshops. Whistler, British Columbia, 2008.

3.10.13. Highway 99 Tunnel Closure System (Seattle)

The Highway 99 tunnel closure system is presently being installed as part of a larger effort to replace the Alaskan Way Viaduct in downtown Seattle. The project is ongoing, running between 2010 and 2015, and so should be considered a future safety system. The intention of the system will be to keep drivers from entering the tunnel when hazards are detected, specifically earthquakes and fires. Sensors will detect seismic activity and smoke, and, should these types of events occur, the system will close the tunnel using gates, as well as activating messages on warning signs.

The system will use seismic and fire sensors to detect hazardous conditions, with that data processed through a central computer. Based on the current conditions detected, the computer will activate the closure of gates on the highway and post warning messages to signs along Highway 99. As the system is still in development, its effectiveness has not yet been determined. However, tunnel fire detection systems have been used elsewhere by the Washington State Department of Transportation with success, prompting their use on this project.

Purpose: Close the Highway 99 tunnel in downtown Seattle when seismic activity or fire is detected.

Status: Installation in Progress

Deployed: 2010-2015

Location: Downtown Seattle as part of the tunnel replacing the Alaskan Way Viaduct.

Components: Seismic and fire sensors, central control computer, road closure gates, DMS.

System Contact:
Bill Legg
State ITS Operations Engineer
Washington State Department of Transportation
Telephone: (360) 705-7994
Email: leggb@wsdot.wa.gov

3.10.14. I-5 Tunnel Fire Detection and Closure Systems (Seattle)

The Washington State Department of Transportation has deployed three fire detection and closure systems in tunnels in the Seattle area. One is located along I-5 at milepost 166 (under the convention center). The purpose of the system is to warn motorists of fires in a tunnel and to close that respective tunnel to traffic. The I-5 system was installed in 1988 and remains active today.

The system is comprised of fire detection sensors and signage that close the tunnel down when a fire is detected. Closures are done via electronic message signs along the roadway and red traffic signals. To date, the system has been activated a few times for fires. However, the sensors are sensitive, and so false positive activations have also occurred over time when fires were not present.

Overall, the system has worked well to date and functions as intended. While WSDOT would consider the deployment of additional systems in other locations as required, there would need to be a physical closure mechanism added. Right now, there is no physical closure mechanism (such as automated gates) to stop vehicles from entering the tunnel, and people have ignored the tunnel closure warnings in the past. Given that the detection sensors are sensitive, a revised design is being planned for other tunnel locations with similar systems on I-90. These are discussed in a following section.

Purpose: Close tunnels on I-5 when fires are detected.

Status: Active

Deployed: 1988

Location: I-5, mp 166 (under the convention center).

Components: Fire detection sensors, system controller, electronic signs, red signals.

System Contact:
Bill Legg
State ITS Operations Engineer
Washington State Department of Transportation
Telephone: (360) 705-7994
Email: leggb@wsdot.wa.gov

3.10.15. I-5 Tunnel Fire Detection and Closure Systems (Seattle)

The Washington State Department of Transportation is currently developing an updated fire detection and suppression system for tunnels located on I-90. They are located at milepost 4 (Mt. Baker), and I-90 at milepost 6 (Mercer Island). Currently, systems similar to those described earlier on I-5 are in use. The updated fire system in the I-90 tunnels will increase the speed and accuracy in which fires are detected by using infrared sensors and allow for early suppression via water and possibly foam before fire department personnel arrive. The purpose of the current system is to warn motorists of fires in a tunnel and to close that respective tunnel to traffic, and the updated system will do the same. The original system was installed in the early 1990's, while the revised system is scheduled to become active in mid-2015.

The updated system will use infrared cameras and spot heat detectors will be used to monitor conditions and identify the presence of fire. If the infrared or the spot heat detectors sense a fire, the TMC operator will be alerted both audibly and visually to the issue. Lighting and ventilation in the tunnel will increase to maximum automatically. The image from the infrared camera that detected the fire will be displayed for the operator as well as the video from the upstream and downstream pan-tilt-zoom (PTZ) cameras. The operator will be given 50 seconds to confirm or dismiss the fire alarm. If no fire is present, the alarm will be dismissed by the operator and all systems will return to normal. If the alarm is confirmed, drivers will be warned of the hazard via variable message signs and lane control signs. Drivers may or may not be directed to evacuate the tunnel depending on the size of the event. Water and possibly foam will be dumped on the fire 10 seconds after the warning is issued. This application will continue until the fire department arrives and confirms that it is safe to turn the suppression system off. Once the event is over, the operator will return lighting and ventilation in the tunnel to normal.

The system that is currently in place has worked well to date and functions as intended. The performance of the future system remains to be seen, although infrared cameras have been running for a year now in a test setup (four cameras). No false positives have been reported and the system has detected several test fires correctly. There was only one fire that the took a while to detect, but that was expected since the fire was shielded from the camera.

Purpose: Detect/suppress fire and close tunnels when fires are detected.

Status: Original system active, updated system under design.

Deployed: 1990s (original), mid-2015 (revised).

Location: I-90, mp 4 (Mt. Baker) and mp 6 (Mercer Island).

Components: Infrared fire detection sensors, spot heat detection, system control software, electronic signs, emergency telephones, PTZ cameras, enhanced ventilation system.

System Contact:
Bill Legg
State ITS Operations Engineer
Washington State Department of Transportation
Telephone: (360) 705-7994
Email: leggb@wsdot.wa.gov

4. CONCLUSIONS

During the course of this work, a number of automated systems were identified as being deployed, past and present, in the western U.S. to address a variety of problems. This includes 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 is 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 feature for most of these systems share is 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 this work.

While many of the staff members contacted during this work were satisfied with their respective systems and would use them again, some systems did present problems. This was particularly true of some weather-related systems, where detecting specific conditions such as icy pavement or low visibility can be a challenge. In these cases, the technologies employed were not yet capable of meeting the overall needs of the system or required careful consideration of sensor placement. Where such challenges were encountered, they have been documented in this synthesis. It is hoped that the lessons learned from such deployments will aid practitioners in developing and deploying new systems in the future while avoiding the pitfalls of the past.

One of the more evident observations made during the course of this work was the lack of evaluation efforts related to each system. This is primarily the result of each system addressing a specific issue outside of the context of a formal research effort. Still, it would be of interest in the future for agencies to make a general evaluation of the different systems to establish some formal metrics regarding their effectiveness. This could consist of general speed studies (i.e., changes in speeds when a system is on versus off) or a comparison of crash numbers before and after deployment. While these evaluations might not represent rigorous statistical analyses, they would provide additional information that could support similar deployments elsewhere in the future.

In many cases, the systems documented in this synthesis were deployed in rural areas. This underscores two points. The first is that many rural safety problems can be addressed through ITS. The second point is 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.

As indicated in the introduction of the synthesis, this document is intended to be a living one. As new automated warning systems are deployed across the western U.S. and come to the attention of the WSRTC and researchers, they will be added to the document. To this end, readers are encouraged to contact members of the WSRTC and the research team if they are aware of any systems that have been deployed, past or present, that do not appear in this document. Contact information for the researchers and state DOT members of the WSRTC is posted on the Consortium's website at: http://www.westernstates.org/Default.html#CONTACTS.

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. This update should require reduced work on the part of the researchers as the existing approach would be reused. The update itself would involve not only identifying new systems but also refreshing current contact information, which is likely to become outdated as time passes.

5. REFERENCES

1 Sisiopiku, Virginia and John Elliott. Active Warning Systems: Synthesis. Journal of Transportation Engineering, Vol. 131, No. 3, 2005, pp. 205-210.

2 Robinson, Mark, Pat McGowen, Ann Habets and Chris Strong. Safety Application of ITS in Rural Areas. United States Department of Transportation, Washington, D.C., September 2002.

3 Abdel-Aty, Mohamed, Mohamed Ahmed, Jaeyoung Lee, Qi Shi and Muamer Abuzwidah. Synthesis of Visibility Detection Systems. Report BDK78 977-11 Florida Department of Transportation, Tallahassee, October 2012. 148 pp.

4 Murphy, Ray, Ryan Swick and Gabe Guevara. Best Practices for Road Weather Management, Version 3. Report FHWA-HOP-12-046, Federal Highway Administration, Washington, D.C., June 2012.

5 Decker, R., R. Rice, S. Putnam and S. Singer. Rural Intelligent Transportation System Natural-Hazard Management on Low-Volume Roads. Transportation Research Record: Journal of the Transportation Research Board, No. 1819, TRB, National Research Council, Washington, D.C., 2003, pp. 255-259.