Evaluation of the Fredonyer Pass Icy Curve Warning System

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

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EXECUTIVE SUMMARY

The Fredonyer Pass Icy Curve Warning System was deployed by Caltrans to increase motorist vigilance and reduce the number of crashes occurring during icy pavement conditions in real-time. The ICWS consists of pavement sensors to detect icy conditions, in combination with dynamically activated signage to provide motorists with real-time warning when icy conditions are either imminent or present. The system is intended to alert motorists of icy conditions, eliciting a decrease in vehicle speeds during such conditions. Consequently, lower vehicle speeds are expected to translate to reduced crashes along the length of the curves which have presented safety challenges in the past.

While the system was initially installed during the summer of 2002, it did not reliably operate in the manner envisioned by Caltrans and required an extensive rebuild, which began during the spring of 2006. The rebuild and subsequent testing and validation of the system required a significant amount of time. As a result, the ICWS was not considered fully operational and reliable until the winter season of 2008-2009. The work presented in this report has evaluated the performance of the ICWS following the rebuild, focusing on the metrics of speed reduction under various conditions and safety performance through crash reduction. In addition, a review of literature pertaining to road condition warning systems was made, along with documentation of winter maintenance, ITS engineering and CHP perspectives of the ICWS.

The results of the statistical analysis of speed data suggest that the system is working as intended and that vehicle speeds are significantly lower. As one would expect, mean speeds were lower when the system was turned on versus off as well as during the day and at night. When general wet weather (snow, rain, etc.) conditions were evaluated, it was found that mean speeds were reduced when the system was on versus off during both the day and at night. The real effectiveness of the Fredonyer ICWS on vehicle speeds was its impact during clear, cold and not dry conditions, when snow melting or general water/ice pooling from the wet and cold environment of the curve locations may produce runoff across the roadway in the target curve and result in ice formation. Mean speed differences exceeding 3 mph were observed during such conditions during both the day and at night at a majority of sites. However, only a limited number of mean speed differences were found to be greater than 5 mph. As the speed readings employed in this evaluation were collected at sign locations in advance of the curves of interest/concern targeted by the ICWS, it is possible that the observed changes in mean speeds reported here are translating into even more significant reductions by motorists as they enter and traverse each curve. When examining different levels of manned chain control versus the system state and time of day, it appears that the greatest impact of the ICWS is when R-1 control is in effect.

In order to determine the safety effects of the ICWS, an observational before-after study using the Empirical Bayes technique was employed. This evaluation determined the effect of ICWS on crash frequencies. The results found that the deployment of the ICWS reduced the number of annual crashes by 18%. As no other changes occurred along the study segment (additional safety improvements, geometric changes, etc.), it is reasonable to attribute this observed safety improvement to the ICWS. Additionally, a crash rate method was used to investigate the effect of the ICWS on crash severities, with a focus on ice-related accidents. The results indicated that the ICWS has reduced crash severities. As a result of reduced crash severities, the system was estimated to provide safety benefits of $1.7 million dollars per winter season during the after deployment study period (2008-2009, on account of time lag in crash data availability). Given that 1 ½ years of after period data was available for analysis, it would be advisable to revisit the safety performance of the Fredonyer ICWS at some point in the future when more years of crash data are available. Overall however, the initial safety evaluation results indicate that the system is having a positive impact on reducing crashes.

From the perspective of winter maintenance personnel, the ICWS is an improvement over typical static metal signage. Observations made over time have indicated that as the winter progresses, the system works better. The use of additional pavement pucks for detection of conditions in multiple lanes could improve system accuracy and reliability. The data produced by the ICWS is not presently employed by maintenance forces for any activity, although the CCTV camera associated with the system's RWIS at the summit is used frequently to obtain visual information on present conditions.

Feedback by ITS engineering indicated that following the rebuilding of the ICWS, it is generally functioning as expected. However, observations over several years of operation have indicated that the system has difficulty identifying road conditions during the early winter. The use of additional sensors in such cases would address this issue. Also, employing data from supplemental sensors (ex. air temperature, precipitation, etc.) could possibly allow the system to compensate for times that roadway surface temperature and condition data is not sufficient in identifying potential icing conditions. When considering similar systems for deployment elsewhere, it is especially important to select roadway sensors that can be tested/calibrated easily and to employ data collection equipment in the system that uses open and easily programmed software.

Finally, feedback provided by CHP indicated that drivers appear to be slowing down when the ICWS is on (particularly in vicinity of the targeted curves) This is only perception though, and there has been no analysis performed by CHP (ex. on ticket records) to verify whether it is in fact the case. It was also believed that crashes over the pass have dropped in recent years, although again, no analysis of data has been performed to confirm this view. The thoughts of CHP on this drop were that it could be related to the ICWS, as well as manned chain control policies employed by Caltrans. In general, the system appears to be accurate in indicating ice conditions.

1. INTRODUCTION

Fredonyer Pass, located in northeastern California, is a five-mile segment of State Highway 36 in Lassen County that has a history as a high-collision location, including multiple fatal crashes involving local residents. The vast majority of these crashes (note in this document, the terms crash and collision may be used interchangeably) occurred when the pavement was icy, despite static signage that Caltrans had installed to increase motorist awareness. To address this, Caltrans deployed a system consisting of pavement sensors to detect icy conditions, in combination with dynamically activated signage to provide motorists with real-time warning when icy conditions are either imminent or present. The intention of the system was to use real-time messaging to increase motorist vigilance and reduce the number of crashes occurring during icy pavement conditions. This system is collectively known as the Fredonyer Pass Icy Curve Warning System (ICWS). It is comprised of two similar but separate warning systems: Fredonyer Summit ICWS and Fredonyer East ICWS.

The technologies employed in each system include a road weather information system (RWIS), which continuously monitors the road surface condition and identifies when icy or packed snow conditions are present; and two extinguishable message signs (EMS), which provide dynamic warnings to motorists when icy or packed snow conditions are present.

One RWIS was placed in the heart of each curve at a location determined by engineering analysis to experience icing conditions most frequently. One EMS was placed on the approaches to each curve at a location to provide adequate braking distance for vehicles headed into an icy curve. A schematic showing the location of the Intelligent Transportation Systems (ITS) elements of the system is presented in Figure 1-1.

The original, vendor-supplied system components were installed during the summer of 2002, including RWIS pavement sensors, RWIS towers, solar panels, and EMS. Over time however, it became evident that this system would not reliably operate in the manner envisioned by Caltrans. Instead, the system would require a rebuild carried out by Caltrans District 2 ITS Engineering and highway maintenance personnel.

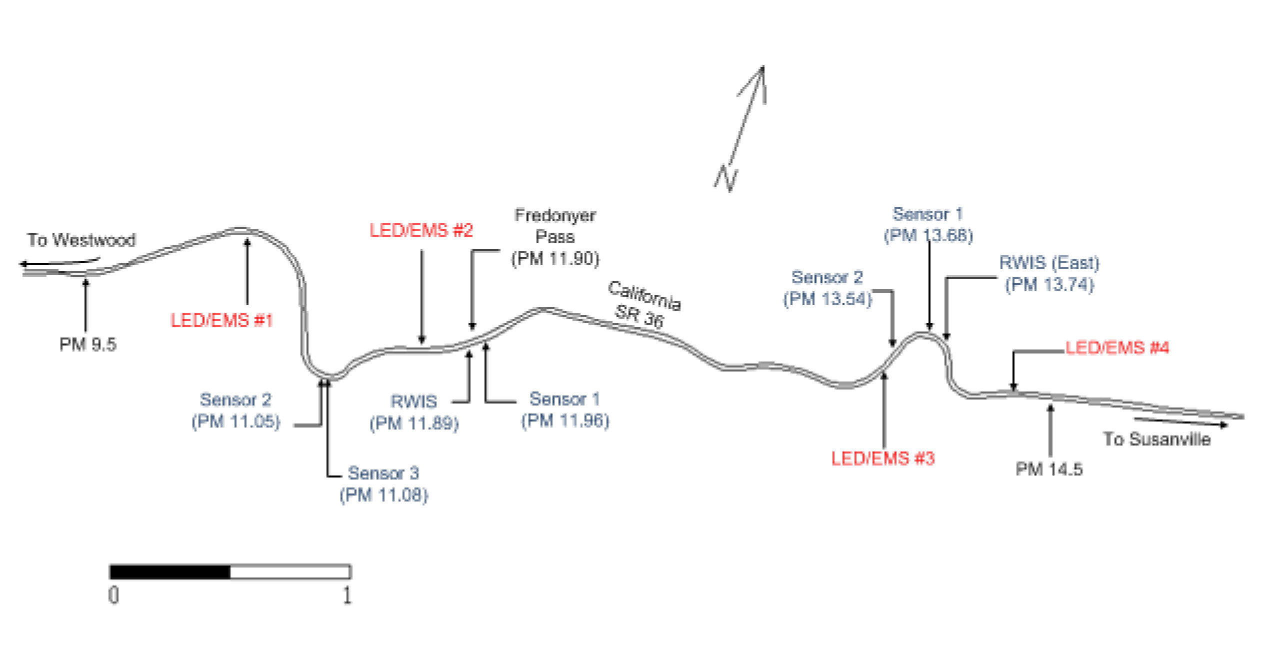

Figure 1-1 Schematic of Fredonyer Pass and ICWS system

While this occurred, the system first went into manual operation – Caltrans maintenance personnel from Susanville would stop at each sign location and turn the messages on and off as warranted. However, this manual operation was determined to be ineffective. In many cases, by the time personnel reached the signs and activated them, maintenance forces had addressed the icy conditions via treatments. As a result, manual operation of the signs was abandoned while the system was rebuilt.

The rebuild of the system itself began during the spring of 2006. This rebuild included the installation of new support infrastructure (wiring, sensors, electronics, etc.) and the development of new operational components to be used in the control of the signage (new data processing scripts to determine icy conditions). The rebuild and subsequent testing and validation of the system required a significant amount of time. As a result, the ICWS was not considered fully operational and reliable until the winter season of 2008-2009. Note that further enhancements to the system were made during the course of 2009, specifically the addition of radar speed measurement units and flashing beacons at all EMS locations.

As a result of the overall problems with the initial functionality of the system, a thorough evaluation of its overall performance and use from an operational, safety and maintenance perspective has not been made to date. Operationally, it is of interest whether vehicle speeds show a statistically significant change between non-icy conditions when a warning message is not posted and icy conditions, when a message is posted. In icy conditions, it would be expected that speeds would be significantly lower, as motorists react to the icy curve warning and adjust their speeds appropriately. From a safety perspective, it is of interest to determine whether crashes have decreased following the deployment of the system[1]. Finally, maintenance

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[1] Note that because of the history of this system, the "after" period for crashes will consist of the winter of 2008-2009, when the system was fully operational and reliable. This rationale will be discussed later in the document.

perspectives are of interest both from a systems perspective (i.e. what the system itself requires in terms of maintenance) as well as from a current winter maintenance perspective.

The following report document consists of six chapters. Chapter 1 has provided an introduction to the problem and the system deployed to address it. Chapter 2 presents a review of literature from similar projects and their results/effectiveness. Chapter 3 presents the results of the analysis of speed data from the study site, while Chapter 4 presents the results of the crash data analysis. Chapter 5 presents the views of Caltrans winter maintenance and California Highway Patrol professionals in Susanville of the system, as well as the experiences of District 2 ITS Engineering regarding the rebuild, operations and maintenance of the system. Finally, Chapter 6 presents a summary of the conclusions made during the course of the work as well as recommendations for future consideration.

2. LITERATURE REVIEW

In evaluating the performance of the Fredonyer Pass ICWS, it was of interest to examine how similar systems have performed in the past. During the course of this work, the researchers identified several systems deployed by other transportation agencies that sought to provide dynamic weather-based warnings to travelers via message signs. While many of these systems did not focus on warnings related to icy roadway conditions, their impacts on vehicle speeds and crashes were still of interest. Note that the focus of this review is on systems that employ message signs (variable message signs, dynamic message signs, etc.) to advise drivers of adverse weather; the studies identified in this chapter do not include systems that employed variable speed limit signage and the like to elicit a change in vehicle speeds. The one exception to this is the Butte Creek Ice Warning System in Oregon, discussed in the next section, which is of interest given its focus on icy conditions.

2.1. Butte Creek Ice Warning System

The most recent project identified during the course of this work which related to weather-based motorist warning was the Butte Creek Ice Warning System in southwestern Oregon (1). This system was deployed in 2005 along a segment of Oregon Highway 140 that experienced icy road conditions. The system employed a Road Weather Information System (RWIS, elevation 5,100 feet) and two static warning signs, located at mileposts 41.7 and 21.7, which read “Watch For Ice When Lights Flash Next 20 Miles”. These static signs were equipped with beacons which flashed when threshold conditions measured by the RWIS were met. Threshold conditions included the presence of a combination of pavement temperature, humidity and wet pavement status. An analysis of the system, which was completed in 2009, examined its impact from three perspectives: accidents, vehicle speeds, and driver surveys.

The accident analysis examined data from a five year period (2003-2008) which included two seasons pre-deployment and three seasons post deployment. A rigorous statistical evaluation was not preformed as part of this work; rather, the overall trends in the number of accidents before and after the system was in place were compared. The researchers found that before deployment, an average of 43 crashes per season occurred, while after deployment an average of 51 crashes occurred. It was noted that the length and severity of winter conditions varied from year to year, making a direct comparison of accident data difficult. In light of this, it was recommended that the safety impacts of the system be reexamined after five full seasons of accident data became available. However, a statistical methodology to employ when conducting this analysis was not discussed.

Also of interest to the Fredonyer project were the results of the analysis of speed data. To measure the changes on vehicle speeds that the system may have had, speed data were collected between September 13, 2007 and April 20, 2008. Data were collected at two locations; one at a point between the ice warning signs (using a Wavetronix SmartSensor HD radar, milepost 35 RWIS site) and one outside the zone (an Oregon Department of Transportation automatic traffic recorder (ATR) site, milepost 16). In total, 19,838 hourly average speeds were calculated from the individual vehicle speeds collected. A full factorial analysis using a three way analysis of variance (ANOVA) was employed to account for directional, site (within or outside the ice-warning system segment) and beacon status factors. Results found that overall speeds were significantly lower when the beacons were flashing, both within the ice-warning system segment and at the ATR site.

Within the ice-warning segment, mean speeds fell by 9.5 miles per hour (mph) overall. Eastbound vehicle average speeds were 10.4 mph, while westbound average speeds were 8.4 mph. Overall speeds were also significantly lower as measured in the ice warning segment compared to those of the ATR site. This was found to be the case regardless of the direction of travel and the status of the system (on or off). Additionally, when packed snow conditions were observed, average speeds at the RWIS site were 43.4 mph compared to 52.6 mph at the ATR site, which was statistically significant. However, despite these findings, the researchers noted that it could not be conclusively determined from the data collected whether the beacons caused drivers to slow down or if poor road conditions caused motorists to drive more cautiously.

The final aspect of the analysis was a survey of drivers to determine their awareness of the system and whether it affected their driving habits. In-person interviews were conducted within the ice warning segment during inclement weather (at sno-parks and rest areas), online to students, faculty and staff at the Oregon Institute of Technology (Klamath Falls), and by mail to a random sample of Klamath Falls residents. The participation in these surveys was 45, 59 and 105 respondents, respectively.

Results of the survey indicated that overall there was strong public acceptance and confidence in the ice warning system. Out of 209 respondents, 186 indicated that they were aware of the system, namely the beacons. A total of 157 respondents indicated that the system resulted in their driving slower when activated. Similarly, 151 respondents indicated that they were more attentive when the system was active. Finally, 152 respondents indicated that they were more cautious when the system was active. Interestingly, when asked what distance from the beacons they perceived they would encounter ice, 124 respondents indicated that they thought they would encounter ice within 2 miles. Such information may be of benefit to take into consideration when planning and locating similar systems in the future[2].

2.2. Nugget Canyon (US 30) Ice Warning System

Nugget Canyon, located on U.S. Route 30 in southwest Wyoming, has a long tangent stretch of roadway with vehicles traveling at 75 to 80 miles per hour leading up to a 600-foot length bridge which has an 8 degree curve as it enters the canyon. Historically, when the bridge was icy and vehicles were traveling too fast, they would cross the centerline, resulting in head-on crashes. Traffic on the roadway was approximately 1,400 vehicles per day (2001) during the winter months, and about fifty percent of traffic was trucks. Anecdotally, there were fatal accidents almost every winter due to ice.

An ice warning system was installed in 2001 by the Wyoming Department of Transportation (WYDOT) (2). The basic system included an in-pavement sensor used in conjunction with atmospheric sensors, and in-field software to interpret the sensor data. Based on one of several conditions, the software would indicate that ice or frost was present, at which time it would activate flashing beacons on a sign warning motorists to slow down because of ice. The system

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[2] Note that the ICWS on Fredonyer Pass are deployed along a segment approximately 3.5 miles in length from end to end.

underwent several modifications in relation to the location of the in-pavement sensor, with the system appearing to detect ice reliably. In fact, the system detected clear ice crystals (i.e. crystals that wouldn't be visible to drivers but could cause a significant loss in friction) very well. The system also sent a page to maintenance personnel when the ice warning sign beacon was activated. There were also capabilities for manual activation and deactivation incorporated into the system and no cameras were installed to verify conditions.

As part of the deployment WYDOT installed traffic counters to record vehicle volumes, classifications, and speed at the site. It was found that motorist speeds dropped 5 to 10 miles per hour when the signs were on, and anecdotally there were no fatal crashes since the system was installed (as of 2005). Public response was both positive (e.g. this helps improve safety) and negative (due to initial inaccuracies in ice detection), but WYDOT personnel were encouraged because the reaction indicated that the signs were at least being noticed.

2.3. Idaho Storm Warning Project

The Idaho Storm Warning Project was initiated in 1993 in response to 18 major accidents on Interstate 84, which resulted in nine fatalities between 1988 and 1993. Poor visibility was identified as a major factor in these accidents (3). The system was located along Interstate 84 on the border of Utah and Idaho. It contained sensors to measure traffic, visibility, roadway, and weather data near the Cotterell, Idaho port-of-entry. The system included four Variable Message Signs (VMS) that provided information to motorists: two were used to provide direct information to the motorist while the others were used primarily by maintenance staff to close the interstate in severe weather. During the evaluation period, the system employed additional automatic traffic counters that recorded the lane number, time, speed, and length of each vehicle passing the sensor site, as well as a closed circuit television camera aimed at five target sites to create a comparison of visibility sensors.

The evaluation of the system was divided into three phases. Phase I developed a speed profile for "ideal" conditions (i.e. high visibility, dry roads, no precipitation, and no wind). This provided a baseline for which post VMS installation data could be analyzed. Phase II analyzed vehicle speeds under various weather conditions in an attempt to isolate factors that resulted in vehicle speed changes. Phase III analyzed vehicle speeds under various conditions during which time the VMS was either on or off in order to determine if the signs were effective. Phase III used 5,790 five-minute intervals over nineteen target days between 1997 and 2000 in which vehicle speeds were recorded by lane and VMS status (on or off). The three phases required seven years to accumulate sufficient data.

The effects of the VMS were found by comparing the results of data collected before and after VMS activation. The evaluation found that during periods of low visibility, when all other conditions were ideal, the signs did not have an apparent effect on driver speed. When the signs were operational during periods of high winds and other extreme weather conditions, drivers in both directions reduced their speeds by 20 mph (3).

Several problems arose from the system being located in a rural remote area. There were power supply problems that required three uninterruptible power sources to be installed. There also were communication problems with existing phone lines that were needed to transmit data from the sensors to the master computer and again to the VMS, which required dedicated twisted pair telephone cables to be installed. Problems also arose from the incompatibility of the DOS-based VMS software and the newer computers that ran them.

2.4. Utah ADVISE

To reduce the risk of accidents during fog and other severe weather events, the Utah Department of Transportation installed VMSs in a fog prone area of Interstate 215 in Salt Lake City. The system's purpose was to advise drivers of the appropriate speed for real-time conditions. Sensors along the roadside continually evaluated visibility; the signs used a weighted algorithm to process visibility data and display messages that reflected the conditions. The system that monitored and sent messages was known as the Adverse Visibility Information System Evaluation (ADVISE) (4).

Data for evaluating ADVISE was collected in three phases. Phase I (winter 1995-1996) recorded the visibility and traffic data prior to VMS installation. During Phase II (1996-1997), UDOT installed the VMS and calibration of the system occurred; data was collected from Phase II but eliminated from the system evaluation because it was deemed unreliable. During Phase III (1999-2000), data collection during VMS activation occurred. Data from Phases I and III was compiled by time and date, and displayed so that the mean, skew, and standard deviation could be compared and analyzed. The mean speeds collected during Phase III were found to be higher than Phase I by 8 mph. When the speed information and standard deviation results were combined, results suggested that the slower drivers sped up. Standard deviation decreased from Phase I to Phase III by 22 percent.

There was a difference in the reduction of standard deviation of 0 percent in dense fog and 35 percent for moderate fog conditions, which means that the system had no effect on traffic standard deviation in dense fog conditions. The researchers felt that this was attributed to drivers' perceptions of "safe speed". They asserted that driver confusion is one of the primary causes of variations in speeds, and that the VMS helped in defining safe speed for drivers who would otherwise rely on their own judgment to gauge safe speeds. The reduction in speed variation reduced the risk of visibility-related accidents, which supported the continued use of ADVISE.

Significant changes in the roadway environment took place during the evaluation period that may have contributed to the increase in mean speed. On December 19, 1995, the speed limit was increased from 55 mph to 65 mph. In 1997, the number of lanes per direction was increased from three to four, which improved the level of service of the road (and consequently, traffic flow and speed). Construction on Interstate 15 in 1997 required rerouting vehicles to the test section, resulting in higher traffic volumes.

2.5. Weather-Controlled VMS in Finland

The Finland Road Administration installed 36 variable speed limit signs along a 12-km long experimental section of Inter-Urban highway E18 beginning in 1992, as well as five variable message signs with the capability of displaying text messages, temperature, and three different sign legends: slippery road, general warning, and road construction (5). All signs were capable of varying brightness. There were two unmanned road weather stations that recorded standard meteorological data and road surface conditions via imbedded sensors in the roadway. The sensors used a pneumatic technique to detect ice on the roadway. The road conditions were classified into three bins: good, moderate, and poor. A road running perpendicular to the experimental road served as a control road and was used to determine the effects of weather on traffic data.

The system was evaluated using an analysis of the speed data from the experimental and control road and through a survey of motorists. Along with the effectiveness of the system, the reliability was evaluated through 139 manual observations of weather, road conditions, and friction measurements during periods of poor weather conditions. The evaluations were cross-tabulated by two factors: actual sign conditions and the appropriate signing estimated by the manually collected data. In 70 percent of cases the speed limit and use of sign for slippery conditions was appropriate. In the remaining 30 percent of cases, the speed limit was considered to be too high or the slippery road symbol was not displayed; the actual speed limit was rarely found to be too low. A pre-deployment evaluation could not be made because the system was installed as the highway was constructed.

The effects of VMS were found by subtracting the effects of adverse road conditions from the total effects found from the experimental road. Only cars traveling in free flow traffic, defined as having at least 5 seconds headway between one another, were employed as speed data. During the analysis, 57 percent of vehicles were found to travel in free flow traffic. The researchers concluded that the mean effect of lowering the speed limit on the experimental test section from 60 mph to 50 mph was 2.11 mph due to the VMS system. When the symbol for slippery road was presented, the decrease in mean speed was 1.5 mph; under these conditions the decrease in mean speed on the control road was 6.03 mph. Under poor road conditions, a decrease in standard deviation of 2.11 mph occurred due to the VMS and zero mph due to the slippery road sign. Through a separate analysis, it was found that the mean speed changes caused by the system were not sufficient enough to make the system socio-economically acceptable (6).

Through a separate study using a series of three questionnaires, the effectiveness of the system was evaluated (7). A survey site was located two miles from the end of the experimental road section. Nearly 600 drivers were stopped and interviewed three, four, eleven and thirteen months after the introduction of the highway and VMS system. The researchers found the following results:

- 91 percent of drivers recalled the posted speed limit
- 66 percent recalled the slippery road sign
- 34 percent recalled the temperature display
- 95 percent of drivers knew that the speed limits were controlled by weather
- 81 percent felt that the speed limit was appropriate, which suggested that criterion used for determining appropriate speed limits was successful
- 95 percent of drivers said that varying speed limits according to prevailing road conditions were useful and enhanced road safety

The findings of this survey suggested that drivers recalled the variable signs somewhat better then fixed static signs (7).

2.6. Travel Advisory Systems and Driving Speed

Ng-Boyle and Mannering examined the impact of out-of-vehicle messages and in-vehicle messages on drivers' speed behavior during adverse weather and incident conditions using a driving simulator (8). While this work employed a simulator as opposed to an evaluation of a specific field deployment, it still offers valuable insights into the potential impacts that systems may have in the field.

The study employed a 12.5 mile simulated length of Snoqualmie Pass on Interstate 90 in Washington State. A total of 51 subjects drove the route and were assigned one of four possible sign conditions (Variable Message Sign message, in-vehicle message, both messages or no message) and one of two types of weather condition (fog or no fog). The researchers focused on driving speed and speed variance to study the possible safety effects of each message-weather combination.

Overall, average driver speed was 53.2 miles per hour. Average driver speed in no-fog conditions was 56.8 miles per hour (standard deviation of 10.2 miles per hour) and 49.5 miles per hour (standard deviation 10.8 miles per hour) in fog conditions. Of specific interest to this project were the results of the VMS message on driver speeds. In general, when speeds over a 3.1 mile highway were examined using an analysis of variance test (ANOVA), the advisory message presented to drivers did not significantly affect mean speeds or standard deviations. The researchers believed that this was the result of drivers slowing down immediately when the observed the message, but then increasing their speed once they felt there was no longer a need to maintain a slow speed.

To determine whether this potential speed compensation was indeed occurring, the researchers examined shorter highway segments of 0.5 miles. Results of this evaluation indicated that driver speeds were impacted by the VMS messages. Specifically, when drivers encountered a VMS message stating “Fog Ahead – Slow Down 45 mph”, they were more likely to slow down. Consequently, the key finding of this work suggests that initially a driver will react to a VMS message related to adverse weather conditions, but once they have traveled a given distance or no longer perceive detrimental conditions, they will once again raise their speed.

2.7. Washington State Ice Warning Evaluation

Carson and Mannering evaluated the effect of ice warning signs on ice-accident frequencies and severities in Washington State. While the signs the researchers examined were static (standard diamond-shaped) and did not incorporate any ITS components (ex. RWIS sensors, VMS), their approach to examining the safety impacts of such signage is of interest. In examining the safety impacts of ice signage, the researchers developed a zero-inflated negative binomial model for Interstates and a negative binomial model for principal and minor arterials for accident frequencies and logit models for accident severities. Each of these model forms was selected to address issues inherent in the analysis of accident data (unequal variance) using traditional approaches (ex. linear regression).

Based on the models developed for each roadway class, the researchers found that ice-warning signs did not have a statistically significant impact on the frequency and severity of ice crashes. In terms of frequency, the presence of an ice warning sign did not significantly affect accidents, but geometric features, including horizontal curve radius, left shoulder width and posted speed limit did. Similarly, accident severity models did not identify a significant relationship between ice warning sign presence and accident severity, although tractor trailer combinations were identified as being more likely to result in a fatality. The researchers concluded that during the analysis period of 1993 through 1995, sign placement practices appeared to be ineffective.

Based on this conclusion, it was recommended that standardized sign-placement procedures be developed and implemented to address ice-related accidents.

2.8. Chapter Conclusion

Based on the literature identified in this chapter, it is clear that only limited work has been completed to date evaluating the performance of ice-specific warning systems. Evaluation of the Butte Creek Ice Warning System, deployed in Oregon found that overall speeds were significantly lower when the beacons of the system were flashing. Within the ice-warning segment, mean speeds fell by 9.5 miles per hour (mph) overall. Eastbound vehicle average speeds fell by 10.4 mph, while westbound average speeds fell by 8.4 mph. Additionally, when packed snow conditions were observed, average speeds at the RWIS site were 43.4 mph compared to 52.6 mph at the ATR site, which was statistically significant. However, despite these findings, the researchers noted that it could not be conclusively determined from the data collected whether the beacons caused drivers to slow down or if poor road conditions caused motorists to drive more cautiously, a key limitation to this evaluation. In addition to Oregon, the Wyoming Department of Transportation installed an ice warning in Nugget Canyon, with speeds found to have dropped 5 to 10 miles per hour when the system warning signs were on, and anecdotally there were no fatal crashes since the system was installed (as of 2005). Additional ITS systems deployed to address various weather concerns yielded different results on vehicle speeds and safety. Given that these systems were not focused on ice warning, they have not been summarized here.

3. ANALYSIS OF SPEED DATA

This chapter presents the results of various evaluations examining the differences in vehicle speeds based on various sets of conditions. These comparisons looked at the system state (on versus off) for a number of different conditions, as well as day versus night, weather conditions (with a focus on clear, cold and dry weather) and manned chain control[3]. While the first two conditions represent a high level evaluation, the latter represent an opportunity to determine whether the system is meeting its true objectives. In clear, cold and dry conditions, a motorist would not expect to encounter icy pavement, but that potential does exist in the two sets of curves that the ICWS has been deployed on. Consequently, it is necessary to determine whether speeds have been significantly reduced under such conditions. Similarly, one would expect that when manned chain control operations are in effect, roadway conditions are quite poor and motorists will already be driving slower. However, when such operations are not in effect, drivers may assume that conditions are better and that they can driver faster.

The following sections discuss the data and analysis methodology employed in this work, as well as the results of the different evaluations that were conducted. The results are presented from a high level downward. Initial results cover the general system state and time conditions, while later results discuss the effect of the ICWS on vehicle speeds for more specific condition sets, namely weather conditions and manned chain control.

3.1. Data

Continuous (24/7) speed data was collected and provided by Caltrans from each of the ICWS sign locations near the beginning of each set of curves. Data were available for the time periods of March 12, 2009 – April 15, 2009, October 1 2009 – March 31, 2010, and October 1, 2010 – April 15, 2011. Note that the data collection units first became active in March, 2009, which is why limited data was available from the initial period. Speed data was measured by radar units mounted to each of the ICWS EMS signs, with data recorded in a comma delimited file to a memory unit at each location. Speed data was downloaded in the field from each memory unit approximately once per month by Caltrans staff. The speed reading recorded by the system was the highest of a series measured for each approaching vehicle. Only vehicle speeds were collected; the system employed in this work was not equipped to collect vehicle type/classification.

While the data from these locations represented vehicle speeds prior to entering each curve, the nature of the system (signs only displaying a message when the system is on) make it likely that most local motorists would already be slowing down after seeing an ice warning message displayed from an advanced distance. Consequently, this data represents information regarding the initial speed behaviors of motorists as they begin to enter each curve. If significantly slower vehicle speeds are observed prior to entering the curves when the system is turned on, it is

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[3] The use of the term "manned" indicates the presence of Caltrans personnel at check points that examine each vehicle to determine whether it is properly equipped with traction chains (or studded tires) based on the prevailing chain control level. This does not mean that chain control is continually staffed; rather, current practice is to have chain control staffed 16 hours a day on weekdays. This includes staffing from 3:00 a.m. until 11:00 a.m. and from 2:00 p.m. until 10:00 p.m. Monday through Friday. Throughout this report, the term manned chain control will be used, although in reality, it is not always staffed.

reasonable to assume that vehicles are traveling slower throughout the length of the curve. Note that one limitation to this evaluation is that speed data was not available from the center of each curve, where vehicles, in theory, would likely be traveling slowest when an ice warning was posted.

Prior to beginning the statistical analysis, data cleanup was required. At the Sign 4 location (the easternmost sign location), Caltrans staff and the researchers observed errors in the timestamps associated with each speed reading. To correct this, the researchers determined the time offset error that had occurred by examining the system state (on/off) from the corresponding sign at this particular set of curves (in this case Sign 3). As both signs operate in conjunction with one another, this allowed for identification of time discrepancies in this manner.

Another issue encountered was that of erroneous data, specifically the presence of continuous readings which were clearly in error. For example, the dataset from Sign 1 (the westernmost sign) on October 1, 2010 contained such erroneous data, which consisted of continuous 16 mph readings from 10:00 p.m. until 5:46 a.m. (1,798 readings total). While the cause of these errors was not known, it was reasonable to hypothesize that the radar unit was affected by a condition which produced frequent readings, possibly ice crystals or other phenomenon. To address this issue, the erroneous data from between 12:00 a.m. and 5:46 a.m. was deleted from the dataset. This was not viewed to be problematic, given the available sample size of data from corresponding time periods which was not affected by such errors.

Finally, Sign 3 experienced a power issue that prevented data from being recorded between November 11, 2009 through November 21, 2009. Additionally, data after November 21, 2009 were recorded with an incorrect date and time stamp. This issue was addressed by identifying corresponding date and time intervals from Sign 4 data which indicated when the system was on. These were matched to the trends recorded at Sign 3, with an appropriate time/date shift employed. The large sample size collected throughout the entire season at this sign was deemed sufficient to address the case of the missing data from the power outage.

3.2. Analysis Methodology

The two-sample t-test (assuming unequal variance) was employed to perform the statistical comparisons of the different system conditions/states using the following formula:

$$t = \frac{\bar{x}_1 - \bar{x}_2 - \Delta}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad (1)$$

where t = test statistic
x_1, x_2 = means of samples 1 and 2, respectively
Δ = change in mean speed of interest (0, 3 or 5 mph in this work)
s_1, s_2 = standard deviations of samples 1 and 2, respectively
n_1, n_2 = sample size for samples 1 and 2, respectively

For demonstration purposes, x_1 would represent the mean of speeds at an EMS during daytime, non icy conditions, while x_2 would represent the mean of speeds at an EMS during daytime, icy conditions. The subscripts of the remaining variables correspond accordingly to these conditions. The hypotheses being tested in this work for the zero mph condition would be as follows:

> H_0: $\mu_1 = \mu_2$, indicating that the mean speeds between non-icy and icy conditions are not significantly different.
>
> H_1: $\mu_1 \neq \mu_2$, indicating that the mean speeds are significantly different (ideally, the icy speeds being lower).

When examining whether mean speeds have changed by a significant value, for example 3 miles per hour, similar hypotheses would be employed, namely:

> H_0: $\mu_1 - \mu_2 \geq 3$ indicating that the difference between mean speeds of more than 3 mph was significant (ideally, the icy speeds being lower).
>
> H_1: $\mu_1 - \mu_2 < 3$, indicating that the mean speeds between non-icy and icy conditions were not significantly different from one another at 3 mph.

To ensure the soundness of the conclusions drawn from the statistical tests, levels of significance corresponding to 0.025 and 0.05 will be employed in evaluating the null hypothesis for the one- and two-tailed tests, respectively. A two-tailed test was employed for evaluating the hypotheses related to changes in speeds greater or less than 0 mph, while one-tailed tests were employed to evaluate the hypotheses that speed reductions when the system was operating were significantly greater than 3 mph and 5 mph. The critical value for these confidence levels was generally 1.96, unless noted otherwise. This value is presented in each of the results tables for reader reference. Based on the results of hypothesis testing, if vehicles show statistically significant reductions in speeds between different conditions, this would indicate that the system is meeting one of its primary objectives.

3.3. Mean Speed Analysis

3.3.1. System On Versus Off

The highest level of speed data comparison performed by this work examined whether vehicle speeds were significantly different when the ICWS was on versus when it was off. Note that this evaluation did not take time of day into consideration (day versus night), weather conditions (wet, clear, cold and dry, etc.), or the level of manned chain control, as these different conditions will be evaluated through tests discussed later in this chapter. The results of the evaluation performed on mean speeds under the system on versus off condition are presented in Table 3-1. Differences in mean speeds were evaluated for 0 mph (i.e. no difference between the sign being on versus off) as well as 3 mph and 5 mph (to determine the extent of the significance of mean speed differences).

At 0 mph, mean speeds differed between the system on versus off condition. Aside from the March-April 2009 period (due to small sample sizes), mean speeds were also found to be significantly different by greater than 5 mph. What this indicates is that all of the observed speed differences between when the system was on versus off were greater than 5 mph overall. Given that only the general state of the system was examined in this initial evaluation, the results generated were expected by the research team.

The reader must keep in mind that the data being analyzed by this portion of testing was collective in the sense that it included all observations, including day and night, good and bad weather, manned chain control, and so forth. In other words, this initial evaluation does not tell the whole story regarding the effects of the ICWS; analysis of more specific conditions was necessary to determine whether it is indeed having the desired effect on vehicle speeds. Such analysis is presented in the following sections.

Table 3-1 Mean speed evaluation results: on versus off

March 12, 2009 - April 15, 2009

Location	Condition	Sample Size	Mean Speed	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Off	27404	56.53			
	On	1556	55.74	**6.14**	-17.14	-32.66
Sign 2	Off	30313	56.95			
	On	994	52.46	**18.57**	**6.16**	-2.11
Sign 3	Off	30336	55.46			
	On	511	48.95	**19.44**	**10.48**	**4.51**
Sign 4	Off	25145	58.39			
	On	202	52.64	**10.47**	**4.99**	1.35

October 1, 2009 - March 31, 2010

Location	Condition	Sample Size	Mean Speed	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Off	69298	55.83			
	On	53042	50.22	**147.17**	**68.44**	**15.96**
Sign 2	Off	71438	55.93			
	On	29797	47.85	**123.73**	**77.80**	**47.18**
Sign 3	Off	103086	54.29			
	On	41022	46.12	**194.52**	**123.11**	**75.50**
Sign 4	Off	108242	57.59			
	On	39472	51.39	**143.05**	**73.82**	**27.67**

October 1, 2010 - April 15, 2010

Location	Condition	Sample Size	Mean Speed	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Off	69900	55.38			
	On	52177	49.78	**141.76**	**65.71**	**15.02**
Sign 2	Off	74189	55.60			
	On	42626	47.67	**150.83**	**93.88**	**55.84**
Sign 3	Off	98460	53.76			
	On	40650	45.63	**189.21**	**119.41**	**72.88**
Sign 4	Off	104478	57.03			
	On	39745	50.62	**146.02**	**77.72**	**32.19**

BOLD indicates significance

3.3.2. Day Versus Night

In order to better understand the impacts of the ICWS under different conditions, mean speeds were evaluated between day and night for times when the system was on versus off. This analysis was performed to determine whether a significant change in speeds occurred when the system was on versus off during the day and night. In order to determine day versus night conditions, sunrise and sunset times for Susanville, California were obtained for each day of data from http://www.sunrisesunset.com/. While this approach did not account for dusk and dawn periods where some limited daylight existed, it did serve to approximate light versus dark conditions. Given the extensive sample sizes of data available, this approximation was acceptable. The results of the analysis performed on mean speeds for day and night conditions are presented in Table 3-2.

Table 3-2 Mean speed evaluation results: day versus night

March 12, 2009 - April 15, 2009

Site	Condition	Sample Size	Mean	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Off-Night	4609	55.69	0.87	-9.57	-16.53
	On-Night	522	55.44			
	Off-Day	22795	56.70	**6.02**	-16.52	-31.56
	On-Day	1034	55.90			
Sign 2	Off-Night	5587	55.65	**12.28**	**5.93**	1.70
	On-Night	300	49.84			
	Off-Day	24726	57.24	**13.57**	**2.42**	-5.01
	On-Day	694	53.59			
Sign 3	Off-Night	5191	54.32	**7.62**	**2.60**	-0.73
	On-Night	216	49.75			
	Off-Day	25145	55.70	**19.29**	**11.40**	**6.14**
	On-Day	295	48.36			
Sign 4	Off-Night	4831	57.15	**6.51 (1)**	**2.83 (1)**	0.38 (1)
	On-Night	93	51.83			
	Off-Day	20314	58.68	**7.2 (1)**	**3.16 (1)**	0.47 (1)
	On-Day	109	53.33			

October 1, 2009 - March 31, 2010

Site	Condition	Sample Size	Mean	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Off-Night	15850	55.61	**85.49**	**44.15**	**16.59**
	On-Night	19568	49.40			
	Off-Day	53448	55.90	**115.23**	**48.69**	**4.34**
	On-Day	33474	50.70			
Sign 2	Off-Night	18556	55.25	**76.02**	**48.94**	**30.90**
	On-Night	10777	46.82			
	Off-Day	52882	56.17	**95.46**	**58.45**	**33.78**
	On-Day	19020	48.43			
Sign 3	Off-Night	28925	53.78	**102.64**	**63.23**	**36.96**
	On-Night	14392	45.96			
	Off-Day	74161	54.49	**164.42**	**104.91**	**65.23**
	On-Day	26630	46.19			
Sign 4	Off-Night	36607	56.86	**94.33**	**45.85**	**13.53**
	On-Night	20128	51.02			
	Off-Day	71635	57.98	**100.33**	**51.65**	**19.19**
	On-Day	19344	51.79			

BOLD indicates significance

Table 3-2 cont'd Mean speed evaluation results: day versus night

Site	Condition	Sample Size	Mean	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Off-Night	12367	54.70	**69.48**	**33.01**	**8.69**
	On-Night	18885	48.98			
	Off-Day	57533	55.53	**115.44**	**49.88**	**6.18**
	On-Day	33292	50.24			
Sign 2	Off-Night	15846	55.36	**95.09**	**62.16**	**40.20**
	On-Night	17960	46.70			
	Off-Day	58343	55.67	**109.65**	**64.60**	**34.56**
	On-Day	24666	48.37			
Sign 3	Off-Night	21042	52.85	**102.54**	**62.28**	**35.44**
	On-Night	17805	45.21			
	Off-Day	77418	54.01	**148.75**	**93.33**	**56.38**
	On-Day	22845	45.96			
Sign 4	Off-Night	30586	56.61	**94.96**	**50.24**	**20.42**
	On-Night	19331	50.24			
	Off-Day	73904	57.21	**104.66**	**54.27**	**20.68**
	On-Day	20414	50.98			
BOLD indicates significance						
(1) Critical value = 1.98						

As Table 3-2 indicates, statistically significant differences in mean speeds were observed during both the day and night when the system was on versus off. With the exception of the first analysis period (March-April, 2009), these differences were significant by greater than 5 mph, suggesting that motorists tended to lower their speed considerably when the ICWS signs were activated. Of course, the inclusion of all data from the times when the signage was on does not present a completely clear picture of whether the system is warning motorists of ice during unexpected (i.e. clear, cold and not dry). One would expect motorists to drive significantly more slowly when bad weather conditions are present, which may be contributing to the significant speed reductions observed in this portion of the analysis. To truly understand whether the system is addressing motorist speeds in conditions where ice may not be expected (clear, cold and not dry) but is present, examination of speed data by system state, time of day and weather conditions in combination is necessary. This is presented in the next section.

3.3.3. Weather Conditions

As discussed in the previous section, one of the primary objectives of the Fredonyer Pass ICWS was to address vehicle speeds (and crashes) which occur during clear, cold and dry (i.e. no atmospheric precipitation) conditions. In such cases, it is likely to be a clear, sunny day with low or moderately low temperatures (slightly above freezing or lower) with no atmospheric precipitation. A driver is likely to travel at a higher speed in these conditions, as they do not expect to encounter an icy roadway. However, in the curve sections where the ICWS has been deployed, icy conditions may be present even on a clear, cold and seemingly dry day. In detecting such conditions and providing drivers with a warning of the presence of ice ahead, one would expect to observe significantly different (lower) vehicle speeds compared to times when then system was off. If this is indeed the case, it may be concluded that the ICWS is likely performing its intended purpose. The following sections discuss the approach employed to identify the different weather conditions of interest and the impacts on vehicle speeds under the various weather conditions identified during both day and night when the ICWS is on and off.

To identify the different weather conditions at the site, RWIS data was obtained from the Fredonyer Summit Pass station that provides some of the data used by the ICWS. This data was obtained via records maintained by WeatherShare (http://www.weathershare.org/). Two types of data were obtained, pavement surface temperature and condition data, as well as general weather data. All of the readings obtained for these elements had a timestamp associated with it, allowing conditions at that specific time to be matched up with individual speed readings from each site. Two lookup tables were set up in Excel and populated with this data; one contained the precipitation data, while the second contained surface temperature data. As the ICWS directly employs information regarding surface wetness, this element was not included as a lookup variable. Next, each individual speed record was matched to the weather conditions in the lookup table that were present at the same time. Each of the different conditions variables associated with the individual speed reading were then classified by their respective scenario (see Table 3-3), which included wet, clear, cold and dry, and clear, cold and not dry for both day and night. In some cases, historical weather data was not available for a specific time period and was classified as “N/A”. Such data was eliminated from analysis, as it was not possible to know if conditions during a given time period were wet, clear, icy, etc. The elimination of these observations was not detrimental to the statistical analysis, as large sample sizes remained for each of the condition scenarios of interest.

Table 3-3 presents a summary of the different clear, cold and dry/not dry (icy) conditions that were identified for specific analysis. Note that this table does not include wet conditions where precipitation was detected either during the day or night and for which the ICWS may or may not have been active. These conditions were statistically evaluated and are presented in the following paragraphs.

Table 3-3 Various weather scenarios identified for analysis

Time of Day	**Conditions**	
	Clear, Cold, and Dry	**Clear, Cold, but not Dry**
Daytime	• No precipitation • Surface Temp < 32F • Surface Status = Dry • ICWS is OFF	• No Precipitation • Surface Temp < 32F • ICWS is ON
Nighttime	• No precipitation • Surface Temp < 32F • Surface Status = Dry • ICWS is OFF	• No Precipitation • Surface Temp < 32F • ICWS is ON

Table 3-4 presents the results of the t-tests performed on mean speeds under precipitation conditions at each sign location. These conditions represent some of the weather events which can be encountered, namely snow. While the mean speeds of the initial March-April 2009 period saw varying significance, the results of the two longer analysis periods were significant in all cases. Not only were mean speeds significantly lower when the system was on overall

(0mph), they were also significantly greater than 5 mph. In fact, the lowest difference in mean speeds observed during wet conditions was a drop of 6.2 mph when the system was on during daylight (Sign 4, 2009-2010).

Table 3-4 Mean speed evaluation results: wet conditions

March 12, 2009 - April 15, 2009

	Site	Condition	Sample Size	Mean	Δ mph	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Precipitation	**Sign 1**	Off-Night	579	57.02	0.44	0.75	-4.48	-7.97
		On-Night	135	56.58				
		Off-Day	8630	56.64	0.47	**2.33**	-12.64	-22.63
		On-Day	491	56.17				
	Sign 2	Off-Night	357	55.37	4.93	**5.07 (1)**	1.98 (2)	-0.07 (2)
		On-Night	59	50.44				
		Off-Day	8949	57.20	1.03	**5.06**	-9.64	-19.45
		On-Day	491	56.17				
	Sign 3	Off-Night	727	55.14	15.81	**7.58 (3)**	**6.14 (4)**	**5.18 (4)**
		On-Night	12	39.33				
		Off-Day	10143	55.65	9.36	**17.85 (5)**	**12.13 (6)**	**8.31 (6)**
		On-Day	140	46.29				
	Sign 4	Off-Night	440	56.64	17.31	**10.02 (2)**	**8.28 (7)**	**7.12 (7)**
		On-Night	6	39.33				
		Off-Day	9006	58.52	4.60	**5.14 (1)**	1.79 (2)	-0.44 (2)
		On-Day	77	53.92				

October 1, 2009 - March 31, 2010

	Site	Condition	Sample Size	Mean	Δ mph	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Precipitation	**Sign 1**	Off-Night	12071	55.88	11.94	**93.37**	**69.90**	**54.26**
		On-Night	3859	43.94				
		Off-Day	48312	55.99	6.65	**93.08**	**51.10**	**23.12**
		On-Day	12543	49.34				
	Sign 2	Off-Night	15678	55.51	16.14	**100.11**	**81.51**	**69.11**
		On-Night	2448	39.37				
		Off-Day	49411	56.31	9.38	**80.25**	**54.57**	**37.41**
		On-Day	7896	46.93				
	Sign 3	Off-Night	22451	54.07	13.66	**88.94**	**69.41**	**56.38**
		On-Night	2606	40.41				
		Off-Day	68115	54.64	7.95	**119.54**	**74.41**	**44.31**
		On-Day	14813	46.69				
	Sign 4	Off-Night	28154	56.87	10.34	**75.02**	**53.27**	**38.77**
		On-Night	4097	46.53				
		Off-Day	66621	58.01	6.20	**78.18**	**40.36**	**15.15**
		On-Day	11590	51.81				

BOLD indicates significance

Table 3-4 cont'd Mean speed evaluation results: wet conditions

	Site	Condition	Sample Size	Mean	Δ mph	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Precipitation	**Sign 1**	Off-Night	7894	54.69	11.21	**80.17**	**58.71**	**44.40**
		On-Night	4368	43.48				
		Off-Day	50023	55.49	7.71	**95.59**	**58.40**	**33.61**
		On-Day	10457	47.78				
	Sign 2	Off-Night	11132	55.34	15.44	**101.97**	**82.15**	**68.94**
		On-Night	3020	39.90				
		Off-Day	51741	55.68	10.73	**93.87**	**67.61**	**50.11**
		On-Day	7462	44.95				
	Sign 3	Off-Night	10664	53.44	13.48	**85.54**	**66.51**	**53.82**
		On-Night	2621	39.96				
		Off-Day	40995	54.00	9.10	**92.99**	**62.34**	**41.91**
		On-Day	7072	44.90				
	Sign 4	Off-Night	22262	56.78	11.27	**84.48**	**61.99**	**46.99**
		On-Night	4649	45.51				
		Off-Day	63477	57.25	7.70	**83.69**	**51.08**	**29.33**
		On-Day	9279	49.55				

BOLD indicates significance

(1) Critical value = 1.98

(2) Critical value = 2.57

(3) Critical value = 2.20

(4) Critical value = 2.77

(5) Critical value = 1.97

(6) Critical value = 2.44

(7) Critical value = 3.18

The highest speed differences observed were during nighttime hours. This was not surprising, as one would expect that motorists would slow down more significantly during the night when visibility is lower and even further hampered by precipitation (namely snow). Aside from the March-April 2009 period, all mean speed reductions observed were greater than 10 mph during night hours when the ICWS was on. Daytime speed reductions when the ICWS was on did not exceed 10 mph, with the exception of the October 2010 – April 2011 period at Sign 2. Of course, all of these speed reductions occurred during inclement conditions when motorists could be reasonably expected to slow down. Consequently, the reduced speeds observed may only be partly attributable to the ICWS.

In order to understand the true impact the ICWS may have on speeds, an examination of speed behaviors when inclement conditions are not present but ice has formed is necessary. These are the conditions where a motorist will not expect to encounter ice and where, if the warning posted by the ICWS is heeded, speeds for the on versus off system state should be significantly different. If the system is meeting its objective of effectively warning motorists to slow down at the target curves, significant drops in vehicle speeds should be observed in this portion of the analysis.

Examining the differences in speeds between clear, cold and dry versus clear, cold and not dry (i.e. icy) conditions at the overall (0 mph) level provided varying results. Significant changes in mean speeds were observed between the on and off system states in almost all cases (the exceptions being three cases in the March-April 2009 period which included small sample sizes). As one would expect, larger differences in mean speeds were observed during nighttime periods, ranging from 2.76 mph to 6.36 mph. Daytime mean speeds also fell when the system was on, dropping by 2.91 mph to 6.80 mph (excluding the March-April 2009 period where small sample sizes yielded widely varying results).

Table 3-5 Mean speed evaluation results: clear, cold and dry/not dry conditions

March 12, 2009 - April 15, 2009

Site	Time	Condition	Sample Size	Mean	Δ mph	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Day	Clear, cold and dry / OFF	858	56.53	0.81	**2.81**	-7.67	-14.67
	Day	Clear, cold and not dry / ON	312	55.72				
	Night	Clear, cold and dry / OFF	46	59.08	1.91	1.56 (1)	-0.88 (2)	-2.52 (2)
	Night	Clear, cold and not dry / ON	82	57.17				
Sign 2	Day	Clear, cold and dry / OFF	982	57.55	5.07	**8.83**	**3.60**	0.12
	Day	Clear, cold and not dry / ON	187	52.48				
	Night	Clear, cold and dry / OFF	37	55.27	8.10	**3.98 (3)**	2.50 (4)	1.52 (4)
	Night	Clear, cold and not dry / ON	28	47.17				
Sign 3	Day	Clear, cold and dry / OFF	731	55.40	11.03	**11.86 (3)**	**8.63 (4)**	**6.48 (4)**
	Day	Clear, cold and not dry / ON	40	44.37				
	Night	Clear, cold and dry / OFF	12	55.41	3.96	-0.41 (5)	-1.62 (6)	-2.43 (6)
	Night	Clear, cold and not dry / ON	86	51.45				
Sign 4	Day	Clear, cold and dry / OFF	661	58.45	6.54	**4.93 (7)**	**2.67 (4)**	1.16 (4)
	Day	Clear, cold and not dry / ON	32	51.91				
	Night	Clear, cold and dry / OFF	5	46.60	-6.36	-1.49 (1)	-2.2 (8)	-2.67 (8)
	Night	Clear, cold and not dry / ON	29	52.96				

October 1, 2009 - March 31, 2010

Site	Time	Condition	Sample Size	Mean	Δ mph	t stat Δ of 0 mph @ 0.05 (1.64)	t stat Δ of 3 mph @ 0.025	t stat Δ of 5 mph @ 0.025
Sign 1	Day	Clear, cold and dry / OFF	2143	54.96	3.38	**25.98**	**2.90**	-12.48
	Day	Clear, cold and not dry / ON	20089	51.58				
	Night	Clear, cold and dry / OFF	2493	55.26	4.42	**33.66**	**10.78**	-4.46
	Night	Clear, cold and not dry / ON	15138	50.84				
Sign 2	Day	Clear, cold and dry / OFF	1915	53.09	3.38	**13.47**	1.52	-6.44
	Day	Clear, cold and not dry / ON	11075	49.71				
	Night	Clear, cold and dry / OFF	2173	54.55	5.17	**26.19**	**11.01**	0.88
	Night	Clear, cold and not dry / ON	7904	49.38				
Sign 3	Day	Clear, cold and dry / OFF	2018	52.49	6.80	**46.00**	**25.71**	**12.19**
	Day	Clear, cold and not dry / ON	11156	45.69				
	Night	Clear, cold and dry / OFF	4602	53.65	6.36	**56.92**	**30.12**	**12.25**
	Night	Clear, cold and not dry / ON	11409	47.29				
Sign 4	Day	Clear, cold and dry / OFF	1972	57.11	5.33	**34.83**	**15.23**	**2.17**
	Day	Clear, cold and not dry / ON	7245	51.78				
	Night	Clear, cold and dry / OFF	5997	57.11	4.83	**56.21**	**21.32**	-1.93
	Night	Clear, cold and not dry / ON	15537	52.28				

BOLD indicates significance

Table 3-5 cont'd Mean speed evaluation results: clear, cold and dry/not dry conditions

October 1, 2010 - April 15, 2011

Site	Time	Condition	Sample Size	Mean	Δ mph	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Day	Clear, cold and dry / OFF	2927	54.50	2.91	**25.34**	-0.79	-18.22
	Day	Clear, cold and not dry / ON	22122	51.59				
	Night	Clear, cold and dry / OFF	2847	53.62	2.76	**21.15**	-1.89	-17.26
	Night	Clear, cold and not dry / ON	14076	50.86				
Sign 2	Day	Clear, cold and dry / OFF	2403	55.28	5.10	**31.46**	**12.95**	0.62
	Day	Clear, cold and not dry / ON	16675	50.18				
	Night	Clear, cold and dry / OFF	3402	54.90	6.58	**44.39**	**24.14**	**10.64**
	Night	Clear, cold and not dry / ON	14548	48.32				
Sign 3	Day	Clear, cold and dry / OFF	5533	52.49	5.56	**55.74**	**25.64**	**5.57**
	Day	Clear, cold and not dry / ON	12813	46.93				
	Night	Clear, cold and dry / OFF	3995	50.93	3.85	**31.16**	**6.89**	-9.28
	Night	Clear, cold and not dry / ON	11224	47.08				
Sign 4	Day	Clear, cold and dry / OFF	5668	56.82	4.42	**44.25**	**14.19**	-5.83
	Day	Clear, cold and not dry / ON	10507	52.40				
	Night	Clear, cold and dry / OFF	6169	55.64	3.64	**37.86**	**6.67**	-14.11
	Night	Clear, cold and not dry / ON	14157	52.00				

BOLD indicates significance

(1) Critical value = 1.98

(2) Critical value = 2.44

(3) Critical value = 2.02

(4) Critical value = 2.57

(5) Critical value = 2.14

(6) Critical value = 2.77

(7) Critical value = 2.03

(8) Critical value = 3.18

In most cases, mean speed differences of greater than 3 mph but less than 5 mph were observed during clear, cold and not dry conditions. The exceptions to these findings were the Sign 2 location during the day (2009-2010 period) and Sign 1 during the day and night (2010-2011 period). In the first instance, a mean speed reduction of over 3 mph was observed, but statistical testing indicated this drop was not significant. In the second instance, mean speed changes of less than 3 mph were observed, resulting in non-significant statistical results. It is encouraging to note that statistically significant changes in mean speeds exceeded 3 mph at the various sign locations, as this indicates that motorists are likely changing their speed behaviors when the ICWS is active. In other words, the system is achieving its intended results; lower vehicle speeds under conditions where ice may not normally be expected.

Finally, in examining mean speed changes greater than 5 mph, it was found that in only limited instances were such statistically significant reductions found. These included Sign 3 during the day and night (2009-2010 period), Sign 4 during the night (2009-2010 period), Sign 2 during the night (2010-2011 period), and Sign 3 during the day (2010-2011 period). Each of these locations resulted in large t-statistics and were the result of large changes in observed mean speeds overall (ranging from 5.56 to 6.80 mph). In general, the lack of significance in speed changes greater than 5 mph at most sign locations was the result of the lack of such notable drops in mean speeds for many observation periods and sites. This is evidenced by the negative and near zero values computed in many instances. In a general sense, this finding was expected, as large changes in speed (i.e. 5 mph or greater) on a clear and cold day even with ice present and the system providing warning cannot be entirely expected from drivers until they have entered a curve. Without speed data from the center of the curves targeted by the ICWS, it remains unknown whether larger drops in mean speeds in excess of 5 mph are being produced by the system. Given that mean speed reductions of at least 3 mph were observed at the majority of sign locations over the analysis periods, it is reasonable to speculate that speed drops within the targeted curves may indeed approach or exceed 5 mph. In such instances, particularly on clear, cold and icy days, the ICWS would indeed be achieving its intended purpose, as such an observable reduction should translate into improved motorist safety.

3.3.4. Manned Chain Control

The final evaluation of mean speeds conducted by this work examined the impacts of manned chain control. One would expect the impacts of the ICWS on speeds when manned chain control, particularly higher levels, is implemented to be minimal. The logic behind this is that manned chain control is implemented during storms when drivers are either less likely to travel or, when they do, are more likely to travel at reduced speeds. Consequently, the evaluations presented in this section focus on general changes in speeds that were observed between speeds when the ICWS was on versus off during periods when manned chain control of some level was implemented. In some cases, speed observations were made during periods when manned chain control of a specific level was in effect, but the ICWS was off. These speeds were compared to those for the same manned chain control level when the system was on. The difference between these two sets of speeds could, in theory, be attributed to the ICWS. In some cases, comparison speeds from times when the system was off were not available. This is particularly true of the more strict manned chain control levels, such as R-1 and R-2.

Manned chain control data was acquired from Caltrans maintenance dispatch records for a brief period pertaining to the crash analysis (July 1, 2008 – December 31, 2009). Given this range of data, the analysis and results presented here are exploratory in nature, covering March through December of 2009 rather than a comprehensive review of all available data (i.e. 2009, 2010 and 2011). They provide a general sense of the speed trends that may be observed when manned chain control is in effect, both when the ICWS is on as well as off.

The manned chain control levels observed for the period of March through December 2009 included Watch signs (i.e. Watch for Ice), R-1M (Modified), R-1 and R-2. A watch sign advises motorists to be aware of the potential for ice on the road. R-1M, or modified, requires chains on all single-axle drive vehicles towing trailers. R-1 requires chains on all commercial vehicles (trucks or buses), while all other vehicles (cars, pick-ups, vans, etc.) must have either snow tread tires or chains on the drive axle. The difference between when R-1M and R-1 control is employed is based on the judgment of winter maintenance operators regarding what the performance of an average vehicle would be under the existing conditions. Finally, R-2 requires chains on all vehicles except four-wheel drives with snow tread tires on all four wheels and provided that tire traction devices for at least one set of drive wheels are carried in or upon the vehicle.

In examining manned chain control, one should bear in mind that the total amount of time each season which such policies are in effect is quite low. In discussing manned chain control with Caltrans maintenance staff in Susanville, it was indicated that controls are in place perhaps 10 percent of an entire season. Given a winter season of October 1st through April 15th totals approximately 4,400 hours, this would equate to manned chain control being in effect for approximately 440 hours (and keep in mind it would not be continuously staffed). Meanwhile, the ICWS is continuously active throughout the entire winter season.

Table 3-6 presents the results of speed comparisons made when Watch signage was posted. When examining the impacts on speeds which Watch signage had in combination with the ICWS being on and off, changes in overall speeds greater than 0 mph but less than 3 mph were observed. The only exception to this was Sign 3 during the day, where an average drop in speeds of 5.08 mph was observed when the ICWS was on. Interestingly, speeds at Sign 2, the Summit system EMS displayed to westbound traffic, actually increased during both the day and the night when the ICWS was on. This sign location is on a downgrade, which might partially explain the higher overall speeds observed, but it is not clear why drivers would travel faster when confronted with two warning messages in different forms. Overall, the results of speed changes when a Watch sign was posted indicate that the combination of this static signage with the message displayed by the ICWS is not influencing drivers to significantly change their speeds.

Table 3-6 Watch signage speed differences

Site	Condition	Sample Size	Mean	Δ mph	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Off-Night	149	55.73	0.81	1.76	-4.77	-9.13
	On-Night	1031	54.92				
	Off-Day	1058	55.84	1.82	**8.25**	-5.38	-14.50
	On-Day	1561	54.02				
Sign 2	Off-Night	166	54.26	-2.24	-3.51	-8.23	-11.37
	On-Night	412	56.50				
	Off-Day	1056	51.85	-1.36	-2.81	-9.02	-13.16
	On-Day	813	53.21				
Sign 3	Off-Night	846	53.89	2.98	**7.29**	-0.05	-4.95
	On-Night	347	50.91				
	Off-Day	2118	54.38	5.08	**17.98**	**7.37**	0.27
	On-Day	612	49.30				
Sign 4	Off-Night	1045	57.44	2.98	**8.48**	-0.06	-5.76
	On-Night	372	54.46				
	Off-Day	1838	58.42	2.48	**7.77**	-1.60	-7.86
	On-Day	505	55.94				

BOLD indicates significance

Table 3-7 presents the results of speed comparisons made when R-1 Modified signage was posted. Only limited comparisons could be performed for this specific manned chain control level, specifically on data from Signs 3 and 4 during the day. These direct speed comparisons revealed that when the ICWS was on during R-1M control, speed changes were significantly greater than 0 mph but less than 5 mph at Sign 3 and significantly greater than 5 mph at Sign 4.

Overall, when the ICWS was on and R-1M control in effect at night, mean speeds ranged from 37.92 mph to 44.18 mph, suggesting that drivers were exhibiting greater caution. Similarly, corresponding speeds during the day ranged from 37.11 mph to 43.37 mph, further indicating that drivers were exhibiting caution.

Table 3-7 R-1 Modified signage speed differences

Site	Condition	Sample Size	Mean	Δ mph	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	564	41.75				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	857	43.37				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	634	37.92				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	617	39.19				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	580	38.07				
	Off-Day	61	41.57	4.46	**7.86 (1)**	**2.57 (1)**	-0.94 (1)
	On-Day	1097	37.11				
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	1032	44.18				
	Off-Day	37	51.64	8.54	**7.12 (2)**	**4.62 (2)**	**2.95 (2)**
	On-Day	725	43.10				
BOLD indicates significance							
(1) Critical value = 1.99							
(2) Critical value = 1.98							

Table 3-8 presents the results of speed comparisons made when R-1 signage was posted. As the results indicate, significant speed changes greater than 0 mph were observed when the ICWS was on at all sites, with the exception of Signs 1 and 2 at night. These speed differences were also greater than 5 mph at all signs, with the exception of Sign 3 at night, where the mean speed difference was greater than 0 mph less than 3 mph. What these results suggest is that the presence of R-1 chain control in combination with the ICWS being on produced significantly lower speeds in most cases. Why significant changes in speeds were not observed at Signs 1 and 2 at night (speeds slightly increased at Sign 1) is not clear. One should note that speeds at each of these signs were low (less than approximately 40 mph overall), indicating that drivers had modified their speeds to reflect the poor roadway and weather conditions present when R-1 signage is implemented regardless of ICWS status.

At this point, a note of explanation is necessary. R-1 (and to a lesser extent, R-1M) signage is posted by Caltrans winter maintenance operators in the field when they observe packed snow and ice conditions along a roadway segment. Consequently, one would expect that the ICWS would only be on when R-1 and R-1M levels were in place, as packed snow or ice would be detected by its sensors. However, one must keep in mind that conditions over an entire roadway segment are taken into consideration when implementing chain control. It was possible that, while conditions at the ICWS sites were detected to be normal (no packed snow or ice), conditions elsewhere along the route (ex. the summit) consisted of packed snow or ice. Consequently, manned chain control would be in effect at the same time as the ICWS was off.

Table 3-8 R-1 signage speed differences

Site	**Condition**	**Sample Size**	**Mean**	**Δ mph**	**t stat Δ of 0 mph @ 0.05 (1.96)**	**t stat Δ of 3 mph @ 0.025 (1.96)**	**t stat Δ of 5 mph @ 0.025 (1.96)**
Sign 1	Off-Night	83	39.83	-0.59	-0.58 (1)	-3.53 (1)	-5.5 (1)
	On-Night	532	40.42				
	Off-Day	619	54.31	13.66	**43.42**	**33.89**	**27.53**
	On-Day	872	40.65				
Sign 2	Off-Night	120	40.00	3.58	1.34 (2)	0.21 (2)	-0.53 (2)
	On-Night	315	36.42				
	Off-Day	795	53.18	14.91	**40.67**	**32.49**	**27.03**
	On-Day	523	38.27				
Sign 3	Off-Night	58	40.55	4.47	**3.89 (3)**	1.27 (3)	-0.46 (3)
	On-Night	336	36.08				
	Off-Day	646	53.84	17.77	**61.53**	**51.14**	**44.22**
	On-Day	461	36.07				
Sign 4	Off-Night	20	53.10	12.61	**11.22 (3)**	**8.55 (3)**	**6.77 (3)**
	On-Night	491	40.49				
	Off-Day	61	55.57	14.49	**17.28 (4)**	**13.7 (4)**	**11.32 (4)**
	On-Day	650	41.08				

BOLD indicates significance

(1) Critical value = 1.98

(2) Critical value = 1.43

(3) Critical value = 1.99

(4) Critical value = 2.07

Table 3-9 presents the results of speed comparisons made when R-2 signage was posted. As expected, no speed data was observed to occur when the ICWS was off and R-2 control was in effect. Given that R-2 signage is implemented during severe winter weather, the ICWS should only be on during such instances, which the data bears out. Overall, the mean speeds of vehicles at the different signs when on during the day ranged from 33.85 mph to 38.72 mph. At night, mean speeds ranged from 35.48 to 38.22 mph at the different signs. In all cases, these mean speeds were lower than the posted speed limits for the targeted sets of curves (40 mph). This reflects driver awareness of the poor roadway and weather conditions present when R-2 control is implemented.

Table 3-9 R-2 signage speed differences

Site	Condition	Sample Size	Mean	Δ mph	t stat Δ of 0 mph @ 0.05 (1.96)	t stat Δ of 3 mph @ 0.025 (1.96)	t stat Δ of 5 mph @ 0.025 (1.96)
Sign 1	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	92	38.22				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	69	38.72				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	60	36.08				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	4	37.00				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	60	35.48				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	55	33.85				
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	110	38.08				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	18	36.27				

BOLD indicates significance

In summary, when examining different levels of manned chain control versus the system state and time of day, it appears that the greatest impact of the ICWS is when R-1 control is in effect. This is encouraging, as roadway conditions under this level can be quite hazardous, and any additional speed reductions that might be achieved in addition to those produced by manned chain control are a benefit. The impact of the ICWS under Watch and R-1M conditions were limited and varied by the specific sign and time of day. While some statistically significant speed reductions were observed, these were cursory and generally less than 3 mph. While the differences between speeds when the ICWS was on and off could not be evaluated for the R-2 chain condition (the ICWS was always on), a general review when the system was on indicated that mean speeds during the day ranged from 33.85 mph to 38.72 mph and 35.48 to 38.22 mph at night. These speeds were less than the posted speed limit, indicating that drivers were exercising greater caution.

3.4. 85th Percentile Speed Comparisons

In addition to examining the statistical significance of mean speed changes at each sign location, the overall changes to 85th percentile speeds was also of interest. Recall that 85th percentile speeds represent the collective speeds that 85 percent of motorists are traveling at or below at a specific point along a roadway. While no statistical analysis technique is available to evaluate the observed differences in 85th percentile speeds, simple comparisons of differences under various conditions are still useful in understanding how different these conditions and system states may produce changes in motorist speed behaviors.

3.4.1. System On Versus Off

The initial analysis level for 85th percentile speeds was the system on versus off state. Results of the 85th percentile speed differences when the system was on versus off are presented in Table 3-10. Note that the results presented here only examine the changes in 85th percentile speeds when the system was on versus off and do not account for the time of day, which is discussed in the following section. In general, 85th percentile speeds fell by varying amounts depending on the analysis period and sign location, with speed changes ranging between 1 mph and 6 mph. This indicates that the speeds at which 85 percent of motorists were traveling were reduced to varying extents. The observed changes in speed were collective for all weather conditions and times of day; consequently, one would expect to see considerable changes in 85th percentile speeds when readings taken during inclement weather and nighttime hours were grouped together.

Table 3-10 85th percentile speed differences – system on versus off

Site	Period	Off (mph)	On (mph)	Difference (mph)
Sign 1	March 2009 - April 2009	61	60	1
	October 2009 - March 2010	61	58	3
	October 2010 - April 2011	60	57	3
Sign 2	March 2009 - April 2009	62	60	2
	October 2009 - March 2010	63	59	4
	October 2010 - April 2011	63	57	6
Sign 3	March 2009 - April 2009	61	56	5
	October 2009 - March 2010	60	54	6
	October 2010 - April 2011	59	54	5
Sign 4	March 2009 - April 2009	63	60	3
	October 2009 - March 2010	62	59	3
	October 2010 - April 2011	62	59	3

3.4.2. Day Versus Night

The second level of examination of 85th percentile speeds separated the data by day and night hours. The methodology for identifying these hours was the same as was used in identifying times during the mean speed analysis portion of this work. The results of 85th percentile speed changes are presented in Table 3-11. As the table indicates, 85th percentile speed changes varied by both day and night. During the day, speed changes ranged from 1 mph to 6 mph (note that the 1 mph difference was observed in the March-April 2009 period with a small sample size). During the night, speed changes ranged from 2 mph to 6 mph (again, note that the March-April 2009 period was comprised of a small sample size). Interestingly, the changes to 85th percentile speeds at Signs 2 and 3 were somewhat higher than those observed at Signs 1 and 4. This indicates that motorists were potentially more cautious once they had passed the initial signs at either end of the corridor and encountered the intermediate signs.

Table 3-11 85th percentile speed differences – system state day versus night

		Day			Night		
Site	Period	Off (mph)	On (mph)	Difference (mph)	Off (mph)	On (mph)	Difference (mph)
Sign 1	March 2009 - April 2009	61	60	1	61	62	-1
	October 2009 - March 2010	60	58	2	61	57	4
	October 2010 - April 2011	60	57	3	60	57	3
Sign 2	March 2009 - April 2009	63	60	3	62	58	4
	October 2009 - March 2010	63	59	4	62	58	4
	October 2010 - April 2011	63	58	5	63	57	6
Sign 3	March 2009 - April 2009	61	55	6	60	58	2
	October 2009 - March 2010	60	54	6	60	54	6
	October 2010 - April 2011	59	54	5	59	54	5
Sign 4	March 2009 - April 2009	63	60	3	62	60	2
	October 2009 - March 2010	62	60	2	61	59	2
	October 2010 - April 2011	62	59	3	61	58	3

3.4.3. Weather Conditions

Table 3-12 presents the results of 85th percentile speed differences during wet weather. In this case, wet weather consisted of times when precipitation was detected in the study area. The methodology employed to identify these conditions (as well as the clear, cold and dry/not dry conditions covered later in this section) was the same as that used in identifying different conditions during the mean speed analysis portion of this work.

As the results indicate, significant changes in 85th percentile speeds were observed during wet conditions between the system on versus off state both during the day and night. During the day, 85th percentile speeds fell by a range of 1 mph to 19 mph, although this range is skewed by observations from the March-April 2009 period which contained limited sample sizes. Still, when the remaining analysis periods were examined, speeds fell between 4 mph and 9 mph. Similarly, 85th percentile speeds fell during the night time hours, ranging between 2 mph and 15 mph (disregarding the March-April 2009 period due to small sample size). These larger night time speed reductions during wet weather were expected, as reduced illumination and visibility were likely to combine in prompting motorists to reduce their speeds significantly. As a result, it is not likely that the ICWS alone contributed to the observed drops in speeds but rather, acted in concert with current conditions to produce a change in motorist speed behavior. Consequently, the true impact of the ICWS should be evident in the trends displayed by the analysis of clear, cold and dry/not dry (i.e. ice formation possible) conditions.

Table 3-12 85th percentile speed differences – wet weather conditions

		Day - Wet			Night - Wet		
Site	Period	Off (mph)	On (mph)	Difference (mph)	Off (mph)	On (mph)	Difference (mph)
Sign 1	March 2009 - April 2009*	61	60	1	63	63	0
	October 2009 - March 2010	61	57	4	61	52	9
	October 2010 - April 2011	60	56	4	60	52	8
Sign 2	March 2009 - April 2009*	63	56	7	61	57	4
	October 2009 - March 2010	63	58	5	62	47	15
	October 2010 - April 2011	63	58	7	63	48	15
Sign 3	March 2009 - April 2009*	61	52	9	61	47	14
	October 2009 - March 2010	60	55	5	60	49	11
	October 2010 - April 2011	59	54	5	59	49	10
Sign 4	March 2009 - April 2009*	61	42	19	63	60	3
	October 2009 - March 2010	61	56	5	62	60	2
	October 2010 - April 2011	62	55	7	62	59	3

* Limited sample size

Table 3-13 presents the differences in 85th percentile speeds between clear, cold and dry conditions and clear, cold and not dry conditions for both day and night. Clear, cold and not dry conditions would be those where there was no atmospheric precipitation (ex. a sunny day), the temperature was fairly low, and there was the potential for water runoff from melting snow to form ice on the roadway surface in shaded curve areas. In such conditions, most motorists would not necessarily expect to encounter ice, and would be, in theory, traveling at higher speeds. In such cases, when the ICWS was on, motorists should slow down to an observable extent.

As the results of Table 3-13 indicate, the 85th percentile speeds did fall considerably during clear, cold and not dry conditions, both during the day and at night. During the day, speeds fell between 1 mph and 5 mph (disregarding the March-April 2009 period due to small sample size). Similarly, 85th percentile speeds fell between 1 mph and 5 mph during the night. Just as previously observed, speeds at the innermost sign locations fell by a greater amount than those at the two outer sign locations. While the changes in speeds were somewhat small (i.e. 5 mph or less), they are indicative that motorists are behaving differently when presented with an ice warning message by the ICWS during conditions when motorists would not otherwise expect ice. Consequently, it is possible that the observed 85th percentile speed changes presented here were part of a larger speed reduction made by motorists as they entered and traversed the target curves.

Note that a discussion of 85th percentile speeds under manned chain control conditions does not follow this section. Such an analysis was not performed based on the overall trends observed in this section, as well as the results of mean speeds presented earlier.

Table 3-13 85th percentile speed differences – clear, cold and dry/not dry conditions

		Day			Night		
Site	Period	Clear, Cold and Dry (mph)	Clear, Cold and Ice (mph)	Difference (mph)	Clear, Cold and Dry (mph)	Clear, Cold and Ice (mph)	Difference (mph)
Sign 1	March 2009 - April 2009*	61	59	2	65	62	3
	October 2009 - March 2010	60	58	2	60	58	2
	October 2010 - April 2011	59	58	1	59	58	1
Sign 2	March 2009 - April 2009*	63	59	4	61	57	4
	October 2009 - March 2010	62	60	2	62	59	3
	October 2010 - April 2011	62	58	4	62	57	5
Sign 3	March 2009 - April 2009*	60	50	10	58	59	-1
	October 2009 - March 2010	58	53	5	59	55	4
	October 2010 - April 2011	58	53	5	57	54	3
Sign 4	March 2009 - April 2009*	63	58	5	53	60	-7
	October 2009 - March 2010	62	60	2	62	59	3
	October 2010 - April 2011	61	59	2	61	59	2
* Limited sample size							

3.5. Chapter Conclusion

The results of the statistical analysis, specifically the analyses performed on clear, cold and dry/not dry data, suggest that the system is working as intended and that vehicle speeds are significantly lower. As one would expect, mean speeds were significantly different overall (0 mph) and differed by greater than 5 mph when examining the speed data for the system on versus off conditions. Of course, this collective analysis tells little about the performance of the system under different conditions, namely during the day and night, as well as during different weather conditions. When day versus night mean speed data was examined, it was once again found that mean speeds were significantly different overall (0 mph) and differed by greater than 5 mph. The general mean speed reductions observed ranged between 5.19 mph and 8.66 mph during the day and 5.72 mph and 8.30 mph during the night.

When general wet weather (snow, rain, etc.) conditions were evaluated, it was found that mean speeds were significantly different overall (0 mph) and differed by greater than 5 mph. During the day, mean speeds during wet weather fell between 6.20 mph and 10.73 mph when the system was on. At night, mean speeds during wet weather fell between 10.34 mph and 16.14 mph when the system was on. Of course, such large changes in vehicle speeds were expected during inclement weather, when visibility and the potential of reduced pavement friction combined to lead motorists to drive more slowly.

The real interest in evaluating the Fredonyer ICWS was to determine its impacts on reducing vehicle speeds during conditions when ice was present but would be unexpected. Such conditions, called clear, cold and not dry in this work, were times when snow melting or general water/ice pooling from the wet and cold environment of the curve locations may produce runoff across the roadway in the target curve and result in ice formation. When the base hypothesis that mean speeds differed from one another overall (0 mph) was examined, statistically significant differences in mean speeds between when the system was on versus off were observed during clear, cold and dry/not dry cases. These differences were also greater than 3 mph. However, only a limited number of mean speed differences were statistically significant by greater than 5 mph. Consequently, it appears that the ICWS is prompting motorists to reduce their speeds by approximately 3 mph in conditions where icy roads are not necessarily expected. Whether this reduction represents a change that translates into long-term safety benefits (i.e. reduced crashes in the curves of interest), remains to be seen. As the speed readings employed in this evaluation were collected at sign locations in advance of the curves targeted by the ICWS, the true changes in motorists speeds throughout the course of the curve remains unknown. It is possible that the observed changes in mean speeds reported here are translating into even more significant reductions by motorists as they enter and traverse each curve.

When examining different levels of manned chain control versus the system state and time of day, it appears that the greatest impact of the ICWS is when R-1 control is in effect. Under R-1 control, mean speeds at almost all sign locations fell by greater than 5 mph when the ICWS was on, a statistically significant change. This is encouraging, as roadway conditions under this level can be quite hazardous, and any additional speed reductions that might be achieved to those produced by manned chain control are a benefit. The impact of the ICWS under Watch and R-1M conditions were limited and varied by the specific sign and time of day. While some statistically significant speed reductions were observed, these were cursory and generally less than 3 mph. While the differences between speeds when the ICWS was on and off could not be evaluated for the R-2 chain condition (the ICWS was always on), a general review when the system was on indicated that mean speeds during the day ranged from 33.85 mph to 38.72 mph and 35.48 to 38.22 mph at night.

In addition to evaluating the impacts of the ICWS on mean vehicle speeds, changes to 85th percentile speeds were also examined. As one would expect, this review yielded similar results to the analysis of mean speeds. Reductions of 85th percentile speeds were observed to varying extents for the system on versus off condition, day versus night, wet weather, and clear, cold and dry versus not dry conditions. Of specific interest once again was the performance of the system during clear, cold and not dry conditions. In such cases, observations from each sign indicated that 85th percentile speeds fell; depending on the site, speeds fell by 1 mph to 5 mph during both the day and night. Once again, the significance of these drops should be taken in context with their collection location. Speed data was collected at the sign locations prior to the targeted curves. Consequently, reduced speeds prior to entering each set of curves may be indicative of greater speed reductions by motorists throughout the entire length of the curve.

Note that one limitation to this work is that the speed collection devices were not capable of collecting vehicle type. Consequently, future work examining the impacts of the ICWS on vehicle speeds under different conditions might consider employing equipment that is capable of collecting such data. This would provide further information on the effectiveness of the system on a vehicle-type basis. For example, it is likely that heavy vehicles are already traveling slower before and within the targeted curves and may not slow down to as great an extent as passenger vehicles when the ICWS is active.

4. ANALYSIS OF CRASH DATA

As the literature review presented in Chapter 2 indicated, limited studies have been completed regarding the safety effects of ice warning systems that use road and weather sensors to gather information and predict the formation of ice. Conceptually, ice warning systems should be more effective than static ice warning signs as they are installed at problematic areas (where ice formation is known to be recurring) and are able to detect or predict ice formation for that specific area. Given that the Fredonyer Pass ICWS was deployed to address safety concerns, a crucial component of the evaluation discussed in this report was the analysis of crash data and trends before and after the deployment of the system. This chapter presents the results of that analysis. An observational before-after study method employing the Empirical Bayes technique was used to determine the effect the ICWS on crash frequencies. The study data, analysis technique and results are presented in the following sections.

4.1. Background

Weather has significant safety impacts on the roadway system. More than 1.5 million weather-related crashes occur in the United States every year, resulting in 690,000 injuries and 7,400 fatalities (9). Slippery conditions, especially icy pavements, can significantly reduce the coefficient of friction between automobile tires and road surfaces, and impair the ability of drivers to operate their vehicles safely. Improving traffic safety under icy conditions is of importance to many state transportation departments.

Static ice warning signs (i.e. fixed metal signs) have been widely used by states with the intent to reduce ice-related accidents. In 1998, a national survey found that only nine states did not use ice warning signs (10). Carson and Mannering (11) conducted a study to evaluate the effectiveness of static ice warning signs in Washington State. It was found that such signs did not have a statistically significant impact on the frequency or severity of vehicular accidents that involved ice. This could have been primarily due to two facts. First, ice formation is a complex process that is both time and location dependent (11). It can form in localized areas (e.g., bridges, shaded areas), which makes it somewhat unpredictable and historical climatic data are of minimal use in the prediction of localized icing without the presence of pavement sensors. Second, many ice-warning signs were posted at inappropriate locations where ice was rarely present, desensitizing drivers to the potential danger. The study suggested that there was a need for standardized sign-placement procedures to reduce the frequency and severity of ice-related accidents (11).

Limited studies were identified on the safety effects of ice warning systems that use road and weather sensors to gather information and predict the formation of ice. Conceptually, ice warning systems should be more effective than static ice warning signs as they are installed at problematic areas (where ice formation is known to be recurring) and are able to detect or predict ice formation. An ice warning system was deployed in 2005 along a 20-mile corridor of Oregon Highway 140 to actively warn motorists of potentially icy driving conditions (the Butte Creek Ice Warning System discussed in Chapter 2) (1). The system consisted of a Road Weather Information System (RWIS) near the summit of the Lake of the Woods Pass. The RWIS was linked to two static signs with flashing beacons that were activated when icy conditions were present. The flashing beacons are activated when threshold conditions at the RWIS site were met (generally a combination of pavement temperature, humidity and indication of wet pavement status) (1). Crash data, including two winter seasons prior to system installation and three seasons after the installation were used to evaluate safety effects of this system. A simple analysis method which only examined the number of crashes per winter season was used to evaluate safety effects of the system. Results revealed that there was no apparent reduction in crashes since the installation of the warning system.

4.2. Data

As discussed previously in this report, there was a time period that the system was not fully operational. Hence, for the safety evaluation presented here, it was important to decide what constituted the before and after period of the study. For this work, the before study period consisted of the time before the deployment of original ICWS. Since the system was not fully operational between the fall of 2002 and the spring of 2008, this time period was not included in the after deployment period. This decision was made to reflect the nature of the system as it existed in the field; while the ICWS was deployed and operated in some fashion (often manually), it was not functioning as it was truly intended. In this sense, any safety effects that might be observed during this initial after period did not accurately reflect those which should occur when the system operated as designed. Consequently, 4.5 years of the before period (January 1, 1998 – June 30, 2002) and 1.5 years of the after period data (July 1, 2008 – December 31, 2009) were chosen for this safety evaluation. (Note that crash data in 2010 were not available during this study due to a time lag in Caltrans' crash reporting database.)

Crash data were obtained from Caltrans' Traffic Accident Surveillance and Analysis System (TASAS) database and the Highway Safety Information System (HSIS) for the study period. Crash information included date and time, post mile, road surface condition, type of accident, etc., as summarized in Table 4-1. The total number of crashes were 56 and 18 for the before and after periods, respectively. Two fatal crashes occurred during the before period, on December 3, 1998 and March 7, 2002. The crash records show that both fatal crashes were under icy conditions. Moreover, among the total 74 crashes, 54 (73%) were involved with icy road conditions. It was found that all of the ice-related accidents happened during winter weather months (from October to March in the following year). Annual Average Daily Traffic (AADT) data were also gathered for the seven study years. Small variations in AADT were identified during the study period (Table 4-1).

In examining the crashes which occurred during the after period, it was observed that the ICWS was turned on during eight of the twelve total crashes. This was not surprising, as one would expect the system to be on during inclement weather when crashes are more likely to occur. Indeed, as information presented in a later section of this chapter (Table 4-5) indicates, the weather during five of the eight crashes during which the system was turned on was reported as being cloudy or snowing. It is interesting that three crashes occurred on days characterized as being clear, as these types of days are the ones that the system aims to target by providing warning of ice when it would not be expected. Note that the status of the ICWS (on versus off) was not incorporated into the statistical evaluation discussed in this work, as the methodology employed is concerned with overall crashes and not the specific conditions present during them.

Table 4-1 Summary of Crash and Traffic Data

Period	Year	No of Months	Crashes (ice-related)	PDO (ice-related)	Injury (ice-related)	Fatality (ice-related)	AADT
Before	1998	12	17	8 (5)	8 (5)	1 (1)	2850
	1999	12	9 (6)	9 (6)	0	0	2850
	2000	12	14 (10)	11 (9)	3 (1)	0	2850
	2001	12	8 (5)	5 (3)	3 (2)	0	2900
	2002	6	7 (6)	3 (2)	4 (3)	1 (1)	2950
After	2008	6	3 (3)	1 (1)	2 (2)	0	2850
	2009	12	9 (7)	7 (5)	2 (2)	0	2850

Note: PDO – Property Damage Only

Table 4-2 shows the geometrics of the five-mile highway section. This information was acquired through past site visits, as well as plan sheets provided by Caltrans. The study roadway was divided into seven segments based on the total number of lanes present and posted speed limits. A passing lane was present in the eastbound (EB) upgrade direction between PM 9.50 and PM 12.27; another passing lane was present in the westbound (WB) direction between PM 11.76 and PM 14.50. The shoulder type of the whole highway section was gravel/cinders. Speed limits were lower within the two major curves where the ICWS' were deployed.

Table 4-2 Geometrics of Lassen 36, PM 9.5 – 14.5

Seg. No.	PM (Begin)	PM (End)	Seg. Length	Lane Width	Total Lanes	No. of Lanes (EB)	No. of Lanes (WB)	Should Width	Speed Limit
1	9.50	10.35	0.85	13	3	2	1	5	55
2	10.35	11.26	0.91	13	3	2	1	5	40
3	11.26	11.76	0.50	13	3	2	1	5	55
4	11.76	12.27	0.51	13	4	2	2	5	55
5	12.27	13.43	1.16	13	3	1	2	5	55
6	13.43	14.10	0.67	13	3	1	2	5	40
7	14.10	14.50	0.40	13	2	1	1	5	55

In addition, the researchers inquired with Caltrans regarding any construction activities which may have occurred during the course of the study period (including the excluded "after" period between 2002 and 2008). The identification of such work, which might include safety-related improvements, was necessary to establish what portion of any reduction or increase of crashes might be attributable to the ICWS versus other changes. A review of Caltrans records indicated that the only construction/improvement activities to occur along the study segments was the extension and replacement existing culverts, which occurred between PM 6.7 and PM 10.4, beginning on December 8, 2009 and continuing for a brief period. No vehicle crashes were identified within/around the construction work zone during this time. This work was not undertaken to address a safety issue on the route, so the ICWS represented the only significant change made to the roadway environment between 1998 and 2009.

Weather was another parameter that ideally would have been considered for this study. However, the RWIS and ice sensors that could provide site-specific information were installed after the before period; consequently, site-specific weather information was only available for the after period. To address the weather data gap in the before period, National Weather Service (NWS) stations close to the study location were sought. Unfortunately, no appropriate NWS station was identified which could provide data for this work. Two nearby NWS stations were deactivated in the 1950's. Other stations only had weather information available which corresponded to the after period. Hence, it was assumed that there were no significant climate or weather pattern changes during the study period. This assumption was supported by a recent Caltrans study (12), which found that although changes have occurred over time (1972 through 2008) in terms of precipitation received by county, these changes have not been significant.

4.3. Methodologies and Data Analysis

The purpose of this analysis was to investigate crash history before and after the deployment of the ICWS and determine if the system positively or negatively affected traffic safety. The impact of the ICWS on traffic safety should be twofold if it was effective. First, it may reduce the number of ice-related accidents as motorists drive more cautiously on icy pavements. Second, the system may help reduce the severity of accidents, again through reduced vehicle speeds. In light of this, the effects of the ICWS on accident frequencies and severities were investigated.

The safety effects of the ICWS can be evaluated through an observational before-after study (13, 14), which is used to determine the change in safety in terms of crash counts:

$$\boldsymbol{\delta = \pi - \lambda} \text{ or } \boldsymbol{\theta = \lambda/\pi} \qquad (2)$$

Where:

δ = crash reduction (or increase);

θ = index of safety effectiveness;

π = the predicted number of crashes in the after period without the ICWS; and

λ = the number of reported/observed crashes in the after period with the ICWS present.

Before-after studies can be grouped into three types: the simple (naïve) before-after study, the before-after study with control groups (the Comparison Group (C-G) method), and the before-after study using the Empirical Bayes (EB) technique. The selection of the study type is usually governed by the availability of the data, such as crashes and traffic flow, and whether the transportation safety analyst has access to entities that are part of the reference group. The selection can also be influenced by the amount of available data (or sample size). The EB method was employed in this work, as it has been shown to have better performance than both the naïve and the C-G methods (13) in addressing problems associated with these approaches (e.g., regression-to-mean (RTM)), and appropriate selection of a before period. Regression to the mean is the potential for a high or low number of crashes to occur during any given year, but over time, for such crashes to hover around a mean annual figure. The EB technique has been effectively used in numerous traffic safety evaluations over the past decade (15, 16, 17, 18, 19, 20, 21, 22, 23, 24).

4.3.1. Observational Before-After Study Using Empirical Bayes

In the EB before-after procedure, an important task is to estimate the number of crashes in the after period had the safety treatment (π) not been implemented. In this case, the estimation being made is for the case where the ICWS was not deployed. To do this, the Safety Performance Function (SPF) for rural two-lane, two-way roadway segments from the Highway Safety Manual (HSM) (14) was used. The form of this SPF is presented in Equation 2. The SPF was used to predict average crash frequency for base conditions (e.g., 12-feet lane width, 6-feet shoulder width, no horizontal or vertical curves):

$$N_{spf} = AADT * L * 10^{-6} * e^{(312)} \tag{3}$$

where:

N_{spf} = predicted total crash frequency for roadway segment base conditions;

$AADT$ = annual average daily traffic (vehicles per day); and

L = length of roadway segment (miles)

Equation 2 is employed for predicting crash frequency for roadway segment base conditions. Crash Modification Factors (CMFs) must be applied to account for the effect of site-specific geometric design features. The HSM provides 12 CMFs for this purpose specific to the rural two-lane, two-way roadway segment SPF. Based on the existing geometrics of the Fredonyer Pass highway section, 6 CMFs needed to be used. These CMFs included shoulder width and type, horizontal curves (length, radius, and presence or absence of spiral transitions), horizontal curves (superelevation), grades, passing lanes, and roadside design. The other 6 CMFs, including lane width, driveway density, and lighting were equal to 1.0, as these features were not present along the Fredonyer study segments. Most CMFs are easy to calculate based on the reference tables or equations provided in the HSM. The CMF for horizontal curves (length, radius, and spiral transitions) is worth noting, as the calculation of this CMF is more complex. This CMF is calculated by:

$$CMF_{hc} = \frac{(1.55 * L_c) + \frac{80.2}{R} - (0.012 * S)}{(1.55 * L_c)} \tag{4}$$

where:

CMF_{hc} = crash modification factor for the effect of horizontal alignment on total crashes;

L_c = length of horizontal curve (miles) which includes spiral transitions, if present;

R = radius of curvature (feet); and

S = 1 if spiral curve is present, 0 if not present, and 0.5 if present at one but not both ends of the horizontal curve.

For the approximately five-mile roadway section in this study, 15 horizontal curves were identified through examination of Caltrans plan sheets, each with varying radii and lengths. There were no spiral curves on this roadway section. Some of the circular curves were connected by short tangent segments (e.g., around 200 feet). In such cases, these curves were treated as a horizontal curve set. For each individual curve, the value of L_c used in Equation 3 is the total length of the compound curve set and R is the radius of the individual curve. The CMF for the consecutive curve set is the aggregated effect of individual curves: $CMF_{hcj} = \prod_{i=1}^{n} CMF_{ij}$, given n individual curves in the jth horizontal curve set. Based on the total number of lanes, speed limit and presence of horizontal curves, the whole roadway section was divided into 15 roadway segments (including 3 horizontal curve sets). Table 4-3 shows segment numbers running from west to east and associated segment lengths. Note that those tangent segments having the same geometrics (number of lanes) and speed limit were combined as a longer segment for simplicity. Actually, this combination has statistical benefits, based on the value of the overdispersion parameter associated with Equation 2 determined by $k = 0.236/L$. As indicated in the HSM (14), the closer the value k is to zero, the more statistically reliable the SPF. Combing those tangent segments with same geometrics could improve the reliability of the predictive model.

The EB technique was used to estimate the expected crash frequency by combining the predictive model estimate with observed crash frequency. The expected crash frequency for an individual roadway segment is computed by:

$$N_{expected} = w * N_{predicted} + (1 - w) * N_{observed} \tag{5}$$

$$w = \frac{1}{1 + k * (\sum_{all\ study\ years} N_{predicted})} \tag{6}$$

where:

$N_{expected}$ = estimate of expected average crash frequency for the study period;

$N_{predicted}$ = predicted model estimate of average crash frequency for the study period;

$N_{observed}$ = observed crash frequency at the site for the study period; and

w = weighted adjustment to be placed on the predictive model estimate.

4.4. Results

The results of the observational before-after study using the EB technique are presented in Table 4-3. The expected number of crashes was 14.08, with a standard deviation of 2.81 crashes. In the analysis, the weighted average *AADTs* was used for both before and after periods since there were small variations among the study years. As a result, the weighted average *AADTs* were 2,873 and 2,850 vehicles per day for the before and after periods, respectively.

Table 4-3 EB Analysis Results

Seg. No	Type of Seg.	Seg. Length (mile)	Observed Crashes during the Before Period	EB Estimated Crashes during the Before Period	Observed Crashes during the After Period (λ)	EB Estimated Crashes during the After Period (π)	Variance of π
1	Tangent	0.61	4	3.10	0	1.02	0.48
2	Horizontal Curve Set	1.05	6	5.07	0	1.68	0.81
3	Horizontal Curve	0.27	5	3.39	2	1.12	0.62
4	Horizontal Curve	0.21	2	1.46	0	0.48	0.24
5	Horizontal Curve	0.11	1	0.78	1	0.26	0.14
6	Tangent	0.35	0	0.64	0	0.21	0.09
7	Horizontal Curve	0.16	2	1.45	0	0.48	0.26
8	Tangent	0.55	5	3.44	1	1.14	0.53
9	Horizontal Curve	0.12	3	1.99	2	0.66	0.37
10	Horizontal Curve	0.11	6	4.33	1	1.43	0.96
11	Horizontal Curve Set	0.46	1	1.53	2	0.51	0.26
12	Horizontal Curve	0.14	8	5.54	1	1.83	1.18
13	Horizontal Curve Set	0.44	9	6.74	1	2.23	1.38
14	Tangent	0.24	3	2.18	0	0.72	0.39
15	Horizontal Curve	0.16	1	0.96	1	0.32	0.18
	Total	**5.00**	**56**	**42.59**	**12**	**14.08**	**7.90**

Cumulatively over the entire study segment, the results show that the Empirical Bayes estimated crashes during the before period were 42.59, which is lower than the observed crashes (56). This could have been due to RTM effect, more severe weather during the before period, and/or other confounding factors. The numbers of crashes that were not ice-related were 18 in the before period and only 2 in the after period. Most of the crashes which occurred between April and September were under dry pavement conditions. The crash rate of non ice-related accidents in the before period was higher than that in the after period. Thus, the crash rate in the before period might be higher than the normal rate and cause the RTM effect.

Based on the analysis results, the general effect of the ICWS on accident frequency can be calculated. Instead of calculating the index of effectiveness (θ) presented in Equation 2, an approximate, unbiased estimate of θ was determined by the approach developed by Hauer (13):

$$\boldsymbol{\theta = \frac{\lambda/\pi}{1+Var(\pi)/\pi^2} = \frac{12/14.08}{1+7.9/14.08^2} = 0.82}$$

The variance of θ was calculated by:

$$Var(\theta) = \frac{\theta^2 * (\frac{Var(\lambda)}{\lambda^2} + \frac{Var(\pi)}{\pi^2})}{(1+\frac{Var(\pi)}{\pi^2})} = 0.08$$

The value of θ indicates that the deployment of the Fredonyer Pass ICWS reduced the number of crashes by 18% during the after period for the study section. It is noted that the crash reduction factor (θ =0.82) applies to annual crashes, not only ice-related accidents during the winter season. This is one limitation of the HSM method, as the Safety Performance Function in Equation 2 is only used for annual crash prediction. Hence, the 18% reduction annual crash is based on the assumption that there were no changes in crashes during the summer seasons of the study period when the system was off. It also is reasonable to conclude that the majority of reduced crashes can be attributed to the presence of the ICWS, as Caltrans records indicated that no other geometric or safety improvements were made to the roadway environment during the study period. While manned chain control was also used along the study route during the before and after period, the proportion of time such policies were in effect compared to the continuous presence and operation of the ICWS were minimal (manned chain controls were estimated by Caltrans maintenance forces to be in effect less than 10 percent of the time per winter season). Consequently, while manned chain control also contributes to the overall safety in the study area, the continuous operation of the ICWS is believed to be a greater contributor to the estimated safety improvement.

In examining the estimates presented in Table 4-3, it is of interest to understand the observed and estimated crash trends both within the curves where the ICWS was deployed to address crashes, as well as the segment of roadway between the two systems. The crash performance within curves is directly of interest in order to understand whether the ICWS may have contributed to a reduction in crashes. Meanwhile, crash performance on the segment between the two systems was of interest as preliminary examination of crash data and general observations by Caltrans personnel had indicated that crashes along this section may have fallen post deployment as well.

In examining the data for the western ICWS, the total number of observed crashes before deployment was 6, while zero crashes were observed to occur along this curve. The Empirical

Bayes estimate of expected crashes for this curve during the after period (i.e. estimating expected crashes without the ICWS present) was 1.68 crashes. Consequently, when comparing the expected number of crashes (1.68) to the number observed (0), it appears that the ICWS may have contributed to a reduction in crashes at this location. Bear in mind that this comparison is provided for informational purposes only; the overall statistical analysis discussed throughout this section represents the true impact of the ICWS on crashes.

In examining data from the eastern ICWS, the total number of observed crashes before deployment was 17, while after deployment only 2 crashes were observed. The Empirical Bayes estimates for crashes for the after period was 4.06 crashes, compared to the 2 crashes observed during this period. Once again, it appears that the ICWS may have contributed to a reduction in crashes at this location.

Finally, when examining crashes between the two systems, a total of 25 crashes were observed during the before period versus 9 during the after period. Note that the length of this segment is greater than those of the two sets of curves where the ICWS has been deployed (2.34 miles versus 1.05 for the western curve and 0.58 for the eastern curve), contributing in part to these higher observed figures. A total of 6.29 crashes were estimated for the after period by the Empirical Bayes approach, which is lower than the 9 crashes that actually occurred during the period. Although a couple of the crashes during this period occurred during the summer months when it was not reasonable to expect the ICWS to be operative, it is not clear whether the system did indeed produce a significant improvement in safety between deployments during the winter months based on the observed data.

So far, the evaluation has focused on the effect of the system on crash frequency and has not investigated its effect on crash severity. The HSM (14) does not provide SPFs for crash severity levels, but it does provide information about the default distribution for crash severity levels on rural two-lane, two-way roadway segments. The default distribution was developed based on data collected in Washington State. The proportions for severity levels and collision types may vary with jurisdictions, let alone a specific site that experienced high crashes. Thus, further analysis was conducted to investigate the crash rates for severity level, as described below.

4.5. Crash Severity Analysis

Based on the crash data provided in Table 4-1, the crash rates (ice-related crashes per winter season) for different severity levels were calculated (Table 4-4). The crash rates in the before period were adjusted by $\frac{AADT_{after}}{AADT_{before}} = 0.99$ to compare with those in the after period. The results show that the crash rate for PDO crashes was reduced from 5.51 to 4.00 crashes per winter season. The crash rate for Injury crashes increased from 2.42 to 2.67 crashes per season, although it was actually reduced when looking at both injured and fatal rates together. Overall, it appears that the ICWS has reduced crash severities. This analysis, however, is similar to the naïve before-after study as it does not take RTM into account. The 4.5-year before period provides a reasonable duration for evaluation, but it would be better to have a longer duration of data (e.g., 3-5 years) for the after period.

Table 4-4 Ice-related crash rates by severity level

Study Period	Crash Rate (ice-related crashes per winter season)				
	Total	PDO	Injury	Fatality	Fatality + Injury (F+I)
Before	8.38	5.51	2.42	0.44	2.86
After	6.67	4.00	2.67	0	2.67

While additional data is necessary to draw more certain conclusions, it appears that the ICWS has provided benefits for motorists in terms of the improvement of traffic safety. The Federal Highway Administration (FHWA) provides information on motor vehicle accident costs by severity level based on the KABCO (K—fatal, A—incapacitating injury, B—evident injury, C—possible injury, and O—PDO) scale (25). The costs per fatal crash (K), evident injury (B), and PDO (O) were \$2,600,000, \$36,000, and \$2,000 respectively in 1994. The Consumer Price Index (CPI) inflation between 1994 and 2011 is 1.49, according to the Bureau of Labor Statistics (26). If updated values are applied to Table 4-4, the total safety benefits of deployment the ICWS per winter season can be obtained. The safety benefit can be calculated by the following equation:

$$SB = \sum_{i=1}^{3} (Crash_{before}^{i} - Crash_{after}^{i}) * Cost_i \qquad (7)$$

where:

SB = safety benefit (\$);

$Crash_{before}^{i}$ = number of crashes for crash type *i* (PDO, injury, and fatal) during before period;

$Crash_{after}^{i}$ = number of crashes for crash type *i* (PDO, injury, and fatal) during after period; and

$Cost_i$ = cost per crash for crash type *i* (PDO, injury, and fatal).

A brief calculation found that the monetary safety benefit of the ICWS is approximately \$1.7M per winter season (present value). This represents an estimation of the financial savings accrued by the ICWS through improved safety following deployment.

4.6. Manned Chain Control Analysis

In addition to the contribution of the ICWS, the use of manned chain control over Fredonyer Pass also has an impact on safety. In light of this, it was of interest to examine whether manned chain control policies may have also contributed to safety improvements over the study segment. To examine this, Caltrans provided chain control log reports for the study segments between July 1, 2008 and December 31, 2009 (the latest date of crash data available). Unfortunately, records prior to this range that corresponded to the before study period were no longer available in Caltrans files. The available data provided an indication of the times that a manned chain control level was employed and removed/changed, as well as the level that was implemented. Note that the data did not indicate whether the chain control was manned or not. When manned chain control is employed, it is more likely that fewer crashes will occur, as drivers will be required to install the necessary safety devices or be prohibited from continuing over the pass. Consequently, the use of manned chain control has direct implications on safety.

Due to the lack of data for the before period, the overall integration of manned chain control levels corresponding to specific crashes could not be incorporated into the statistical modeling process. Even if such data were available, it would still have been challenging to directly employ owing to one of the limitations of the EB approach, the use of crash modification factors for crash estimation. This limitation stems from the nature of CMF's, which are typically developed for general roadway conditions (number of lanes, lane width, etc.) and do not necessarily incorporate region specific elements that may contribute to safety, such as manned chain control levels at the time of a crash. For this work, no CMF's were identified which employed manned chain control levels as a model input. The consequence of these limitations was that only an empirical evaluation of the role that manned chain control played in safety over Fredonyer Pass is possible at this time.

Table 4-5 Crashes versus manned chain control level and ICWS status, after period

No.	Date	Time	Post Mile	Dir. Of Travel	Contrib. Circumstances	Severity	Killed	Injuried	Weather	Road Surface	Lighting	Chain Control	ICWS State
1	11/17/2008	8:20	11.09	EB	Speeding	Injury	0	1	Clear	Snowy, Icy	Daylight	None	off
2	12/19/2008	14:04	12.54	EB	Improper Turn	Injury	0	1	Cloudy	Snowy, Icy	Daylight	None	on
3	12/28/2008	9:00	12.52	WB	Speeding	PDO	0	1	Raining	Snowy, Icy	Daylight	None	off
4	1/5/2009	10:45	12.51	EB	Speeding	Injury	0	1	Cloudy	Snowy, Icy	Daylight	None	on
5	1/7/2009	9:45	13.05	WB	Speeding	PDO	0	1	Clear	Snowy, Icy	Daylight	None	on
6	1/13/2009	7:50	13.84	WB	Speeding	PDO	0	1	Clear	Snowy, Icy	Daylight	None	off
7	1/16/2009	9:26	13.49	WB	Speeding	PDO	0	1	Clear	Snowy, Icy	Daylight	None	on
8	4/2/2009	14:15	12.95	WB	Influence of Alcohol	Injury	0	2	Clear	Dry	Daylight	None	on
9	11/12/2009	7:40	14.34	WB	Other Than Driver	PDO	0	1	Cloudy	Snowy, Icy	Daylight	**R-1M**	on
10	11/17/2009	22:30	11.65	WB	Speeding	PDO	0	2	Cloudy	Snowy, Icy	Dark	**R-1**	on
11	11/18/2009	14:16	10.99	WB	Speeding	Injury	0	1	Clear	Snowy, Icy	Daylight	None	off
12	12/9/2009	14:04	12.62	EB	Improper Turn	PDO	0	1	Clear	Wet	Daylight	None	on

Note: ICWS state corresponds to the signage/system the driver would have most recently encountered

As the data in the table indicates, ten of the twelve crashes that occurred during the after period were during times when manned chain control was not active. At the time of most crashes however, roadway conditions were recorded as being snowy/icy. Bear in mind that these conditions are identified by responding police officers in the crash report, and are not necessarily indicative of the true surface state. However, in eight of the twelve crashes, the ICWS was also activated, indicating that the recorded road surface condition was accurate. Interestingly, of the twelve crashes, eleven occurred during daylight hours. Six crashes occurred at or before 9:00 a.m. which indicates that slick roads during the morning commute period may still be unexpected by some motorists, despite the ICWS. Note that both crashes that occurred under manned chain control conditions happened at times when the ICWS signage was activated, as one would expect, although at different times of day.

Only one crash occurred during a time when manned chain control was active. This crash, on November 17, 2009 at 10:30 p.m., occurred during R-1[4] control. This level of manned chain control had been in effect for 1 hour and 20 minutes, having been implemented at 9:10 p.m. The contributing cause of the crash was speeding, which resulted in a sideswipe between two vehicles. The recorded vehicle movements prior to collision were the first vehicle (the vehicle primarily making impact) slowing or stopping and the second vehicle stopped. Consequently, it is not entirely clear whether potentially slick roads contributed to this crash in any definitive manner. As the crash occurred at post mile 11.65 traveling westbound, each vehicle would have passed the activated EMS for the eastern ICWS, as well as been approaching the western ICWS, which was also on at the time.

The second crash, which occurred on November 12, 2009, was a vehicle overturn where the vehicle ran off the road (no apparent contributor was cited in accident records). Manned chain control was not active at the time of the crash (7:40 a.m.), but was implemented shortly after, at 7:58 a.m. Whether this activation was the direct result of the crash and existing road surface conditions is not clear; what is evident is that following the crash, level R-1 Modified [5] was implemented. The ICWS was active at the time of the crash, indicating that there were potentially slick roads. However, the location of the crash at postmile 14.34, with the direction of the vehicle westbound, indicates that the vehicle was still traveling along a tangent portion of roadway (shortly prior to encountering the easternmost EMS). Consequently, the ICWS message may not have yet been viewed or viewed for only a short time before the crash.

In summary, the number of crashes which occurred under (or shortly before) manned chain control during the after period was two. Consequently, two conclusions may be drawn from the empirical analysis made in this section. First, given that manned chain controls are implemented during poor weather and roadway conditions, it is reasonable to observe a low number of crashes during under them. Second, although “before” period manned chain control data is no longer available and could not be accounted for in the statistical approach employed in this chapter, the benefits (i.e. a low number of manned chain control crashes during the after period) can be assumed a continuing trend/pattern from the before period. Since manned chain control levels/practices haven’t changed significantly between the before and after period, it could be assumed that the statistically measured safety improvements discussed in the previous sections were largely due to the presence of the ICWS.

4.7. Discussion

Construction and other work zone activities on this study roadway segment could affect traffic safety. According to Caltrans’ records, there was only one construction activity (extending and replacing existing culverts) that occurred between PM 6.7 and PM 10.4, starting on December 8, 2009 and continuing for a brief period. No vehicle crashes were identified within/around the construction work zone during this time. Hence, the safety evaluation of the ICWS was not influenced by construction activities.

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[4] R-1: Chains are required on all commercial vehicles (trucks or buses). All other vehicles (cars, pick-ups, vans, etc.) must have either snow tread tires or chains on the drive axle.

[5] R-1M: Chains are required on single-axle drive vehicles with trailers.

Compared with ice warning signs and the Butte Creek ice warning system (1, 11), the Fredonyer Pass ICWS appears to have produced greater effects on traffic safety. Bear in mind that the Oregon study employed a basic safety evaluation, as the focus of that project was an evaluation of vehicle speed and motorist survey data. This may be due in part to the technologies used by Oregon as well. In the ICWS, RWIS and ice sensors were deployed at several locations where ice was prone to developing, which not only increased the accuracy of ice detection, but also reduced false alarm rates. Malfunction of a sensor did not significantly impact system performance. As a result, system reliability was improved. Moreover, the EMS signs of the ICWS were placed close to the curves where ice conditions were historically of concern. When the EMS were activated, motorists were likely to encounter ice within a short period. This was likely to increase motorists' confidence in the system. In the Butte Creek study (1), evidence showed that there were many days when the road conditions were dry and clear at the beacon sites and drivers traveled several miles before encountering ice. Thus, the design approach of the Fredonyer Pass system is also critical to the success of such ITS systems.

Across the country, many types of ITS have been deployed to reduce weather-related accidents. However, as noted in the HSM (14), knowledge regarding the quantitative effects of ITS on reducing weather-related accidents is limited. No Accident Modification Factors (AMFs) have been developed for weather issue treatments. Consequently, the results from this study are useful to have a better understanding of safety effects of ice (or icy curve) warning systems. While still a relatively recent deployment, the initial results from the Fredonyer Pass ICWS provide an understanding of the safety effects and benefits of ITS for addressing site-specific weather issues on rural highways.

4.8. Chapter Conclusion

This chapter presented analysis and results of the safety effects of the Fredonyer Pass ICWS. An observational before-after study with EB technique was used to determine the effect of ICWS on crash frequencies. The results revealed that the deployment of the ICWS reduced the number of annual crashes by 18%, which corresponds to an AMF of 0.82. Furthermore, a crash rate method was used to investigate the effect of the ICWS on crash severities, with a focus on ice-related accidents. The results showed that the use of ICWS has reduced crash severities. As a result, the system has potentially provided safety benefits of $1.7 million dollars per winter season during the "after deployment" study period.

While the results presented in this chapter are encouraging, caution is warranted in their interpretation. First, because of the nature of crash databases and data availability, combined with the timing of this evaluation, only 1 ½ years of after period data was available for analysis. While the Empirical Bayes approach employed in this work has been developed to accommodate cases of limited data, it would be advisable to revisit the safety performance of the Fredonyer ICWS at some point in the future when more years of crash data are available. Second, while the lack of any additional construction/safety improvements aside from the ICWS allowed for the assumption to be made that most of the observed safety improvement along the study segment could be attributed to the ICWS, future work should consider a more focused evaluation. Such an analysis would consider only the winter months and require the development of a specific Safety Performance Function. The development of such SPF's can be quite costly, which is why such an approach was not employed in this work.

When considering the implementation of manned chain controls over the pass, only 2 of 12 crashes occurred under (or shortly before) such conditions. Consequently, two conclusions were drawn from the empirical analysis performed. First, given that manned chain controls were implemented during poor weather and roadway conditions, it was reasonable to observe a low number of crashes during manned chain control. Second, although before period manned chain control data was no longer available and could not be accounted for in the statistical approach employed in this chapter, the benefits (i.e. a low number of manned chain control crashes during the after period) could be assumed a continuing trend/pattern from the before period. While manned chain control has historically been used on this route, including during the entire duration of the before and after period, the amount of time such control is active comprises a small portion of that period (approximately10 percent of the time per season). Consequently, it is probable that the statistically measured safety improvements discussed in the previous sections were largely due to the presence of the ICWS. This does not mean that manned chain control policies have not also had a positive impact on safety, as they undoubtedly have. Rather, all other things constant, it appears that the addition of the ICWS, which is continually present (compared to the limited presence of manned chain control) has improved safety.

5. MAINTENANCE AND OPERATIONS

In addition to evaluation of the impacts of the ICWS on motorist speeds and accident history, it was of interest to understand how the system is currently viewed by winter maintenance personnel, electrical engineering staff responsible for the system, and those who may frequently observe the system in operation and its potential impacts driver behaviors. The following sections present information obtained during the course of interviews with Caltrans highway maintenance and electrical engineering staff, as well as California Highway Patrol (CHP) personnel.

5.1. Caltrans Susanville Maintenance

In order to better understand the ICWS, its impacts, and its perceived effectiveness from the standpoint of winter maintenance personnel, a telephone interview was conducted with Galen Roberts, Susanville West Maintenance Supervisor. Maintenance operations for State Route 36 at Fredonyer Pass are handled by Caltrans maintenance staff out of the Susanville maintenance yard, making it logical to obtain feedback related to the ICWS from personnel at this site. A series of questions pertaining to different aspects of the system were posed, with feedback presented in the following paragraphs.

The first question of interest was related to general thoughts on the ICWS, specifically since it became fully operational in the spring of 2009. From the view of the maintenance supervisor, the ICWS is a good system with the visual aspects (electronic signage) it incorporates being an improvement over typical static metal signage. The nature of the visual presentation was thought to be a more effective means of conveying information to motorists, and the ability of the system to turn the message on and off as conditions warrant is also an improvement over static signage, which is always “on”. By turning the message on and off, the system may receive more notice from motorists and raise awareness of deteriorated conditions. In general, as the winter progresses, maintenance’s perception is that the system works better, with the easternmost system performing the best. Ice is anticipated from a maintenance perspective in both sets curves whenever the system is active for one set of curves.

While the system is beneficial overall and does have positive aspects, there are still crashes happening on Fredonyer Pass[6]. From the maintenance perspective, there are still more “tweaks” required of the system. Specifically, the use of additional pavement pucks for detection of conditions in multiple lanes was cited as one such improvement. Maintenance has observed that at specific points in the curves targeted by the ICWS, the outer lanes develop ice before the roadway centerline does. Depending on the location of the various detection pucks for each specific site, this ice formation can sometimes go undetected for longer than it should. This results in maintenance crews complaining that the system should be turned on based on the conditions they are observing, when in fact it is still off. In addition, the thought was expressed that if the EMS signs could be used post other messages, they might be able to provide additional information to motorists during other times of the year.

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[6] Mr. Roberts indicated that one such crash involved a fatality and occurred on Christmas Eve, 2010. Note that this crash was not included in the crash analysis presented in the previous chapter, as its specific information had not yet become available in the TASAS database at the time of this work.

In order to understand how Fredonyer Pass is maintained during various weather conditions, information specific to staffing was of interest. Staffing for winter maintenance on Fredonyer Pass always includes one vehicle (i.e. snow plow) dedicated to Lassen Rt. 36 when it is snowing. If conditions are particularly bad, a grader is also employed, and an additional snow plow can also be dispatched. During normal conditions (i.e. no weather) just one snow plow is on patrol from postmile 22 westward. A patrolling vehicle is planned for 24-hour-a-day, 7-day-a-week operations from roughly December to March. Consequently, State Route 36 was traveled several times per day by maintenance staff during the winter months.

Route 36 is the priority for treatment because of its high commuter traffic levels. Consequently, this is where the most effort and financial resources are allocated. When conditions warrant, manned chain control is employed. The decision to use manned chain controls (and the levels employed) is determined by the snow plow operators (and in rare instances [5% of the time] California Highway Patrol officers). Manned chain control is used to ensure that motorists are complying with the specified levels. This manned control is performed for 16 hours per day 5 days a week in order to capture the commuter traffic periods during weekdays.

Treatment methods were also of interest to this work, particularly from a safety/crash analysis standpoint, as changes that occurred over time may have led to reduced crashes, making it less clear what portion of any safety improvement could be attributed to the ICWS. Anti-icing chemicals were used during “bluebird” weather – i.e. several consecutive days without snowfall and with warmer temperatures – to protect against adhesion of frost, which is a primary source of crashes on the curves. Presalting is used in advance of a storm to prevent snow and ice adhesion to the greatest extent possible. During snow events, snow plows may disperse salt, cinders, or a mix of the two. Ice Slicer™ is also employed as conditions warrant (this is a product that melts snow and ice which is harder than salt and softer than sand). The application rates of these materials begin at about 250 pounds per lane mile and can rise to 500 pounds per lane mile, maximum, depending on conditions. Some locations over Fredonyer Pass are treated with materials three times per day in order to address snow and ice during a storm. The materials (anti-icers, salt, cinders and ice slicer) have been used for a long time and have not changed in recent years (i.e. since at least 2008).

Given that the ICWS employs various detection sensors and RWIS data, it was of interest to determine whether Susanville maintenance forces refer to the data produced by the overall system in conducting their work. At present, data from the National Weather Service data is consulted before and during storms to plan and understand current and future conditions. In addition, the Closed Circuit Television cameras deployed throughout the area (including at Fredonyer Summit) are checked to get a visual confirmation of current conditions. The use of CCTV images is the extent to which data from the ICWS is used, as RWIS information is not consulted. Aside from these electronic data sources, additional data comes from operators in the field who may report back conditions to the Susanville yard. In addition, the maintenance supervisor will go out into the field during a storm, especially when there is snow pack on the roads, to observe conditions and coordinate operations.

As mentioned in a previous paragraph, changes in maintenance practices and materials made since the spring of 2009 were of interest to this work, as such changes could produce safety (and speed reduction) improvements apart from those generated by the ICWS. Consequently, it was necessary to determine whether such changes had occurred in order to potentially account for them in the different analyses completed during this project. Maintenance indicated that the only major change which had occurred in operations over Fredonyer Pass was a shift from 24-hour per day manned chain control down to 16 hour enforcement during the current winter season. As manned chain control typically occurs during the worst storm events when motorists are likely to reduce their speed accordingly (as observed in the analysis of speed data), this change was determined to have a minimal impact on the analyses performed.

From the perspective of maintenance forces, the ICWS does not present much trouble (note that the ICWS is not maintained by Susanville maintenance forces). Crews are careful when plowing snow not to hit the solar panels associated with the RWIS' of the system, although their location away from the road itself helps in this regard. During general maintenance activities (i.e. summer work), care must be taken not to damage the wires and in-pavement sensors of the system when performing crack sealing and grinding operations. Reconstruction and rehabilitation work in the future will need to develop plans for handling the ICWS during construction activities.

5.2. Caltrans District 2 ITS Engineering

In addition to obtaining the viewpoints of the system from a winter maintenance personnel perspective, it was also of interest to this work to record the views and experiences of ITS Engineering personnel in Caltrans District 2. In order to obtain the history and perspectives of the ICWS from an ITS Engineering viewpoint, the researchers interviewed Ken Beals and Jon Miller (Jimmie Munday and Dennis Price also provided feedback via Jon Miller) of the District 2 staff, who have been involved with the various design, operational, electrical and maintenance aspects of the ICWS over the course of its existence and were extensively involved in the system rebuild. The following paragraphs present a narrative of information related to various aspects of the ICWS from an ITS Engineering point of view.

Before discussing the present state of the ICWS, a historical overview of the system and its rebuild is necessary. As it was originally constructed, the ICWS had problems with data collection and the connection between the system controller and the EMS signs. The subsequent rebuild of the system corrected these problems. In addition, there were also issues with understanding how the system used incoming data, as the vendor did not provide information on how the system worked. Consequently, an empirical approach was employed to understand how data was used and to develop algorithms to make the best use of that data in the system.

In examining how the system operated, two troubling conditions were observed. First, on days which the weather was clear and cold, the system would leave the signs on much longer than necessary. This was the result of the sensors reporting "wet" or "trace moisture" conditions, as they had not been completely dried off through direct sunlight. Three of the system sensors were located in shaded areas for most of the day and often reported such false condition readings. The vendor had provided two algorithms for the sensor operations (details unknown for proprietary reasons), with one algorithm providing more consistent results compared to the other. Consequently, the use of the more accurate algorithm was observed to provide improved (although not perfect) operation of the system in clear and cold conditions.

The second condition of concern became present with the start of fresh snowfalls. The roadway surface would be relatively warm, and packed snow would trap water on the pavement surface that would be detected by the surface sensor as being just above freezing. Consequently, the surface sensor would not report an ice condition despite the road surface being snow packed.

This issue was corrected by employing an additional system trigger that identified wet conditions with the pavement surface just above freezing (<32.4 degrees F).

Confirming the concerns raised by maintenance personnel in the previous section, it was found during the rebuilding of the system that the placement of the pavement sensors was not optimal. Observations indicated that the system was being controlled by a single sensor in a majority of instances. Of course, moving the sensors after installation was not possible, but this issue did highlight the need for initial design work in future applications to locate sensors properly for future deployments[7].

Finally, when rebuilding the ICWS, it was determined that two of the EMS signs were not properly installed for viewing from the roadway/driver position. The primary issue was the LED field had a relatively small field of view, which resulted in the sign not catching the driver's attention. This issue was addressed by adding two alternating flashing beacons to each of the four signs employed in the system to enhance their visibility.

It was also of interest to document what maintenance was required to the ICWS following its rebuild. At present, a visual inspection of the surface sensors is made before each winter season. This inspection has found that crack sealer has been applied over sensors in some cases, requiring a cleaning with acetone. During this check, each sensor is also tested for proper operation by manually applying water. Experience has found that the surface sensors do fail and must be replaced. This represents a major operation requiring core drilling and saw cuts to the pavement. This has been an infrequent occurrence in recent years (one sensor replaced in the past four years), but has occurred several times over the longer life of the system. Replacement of the first puck also resulted in lessons learned. This included taping off the puck to avoid getting epoxy on the sensor during installation.

At the controller location, several maintenance aspects require discussion. The fenced enclosure has made it harder to change batteries out because of the extra distance required to carry them to and from the cabinets. The fencing also traps snow inside the enclosure, making access to the cabinets more difficult during winter when access is often required. Within the system controller cabinets, cleaning of the batteries and filling them with water was periodically required. During this maintenance, battery shelves also needed to be cleaned and repainted where acid had spilled onto them.

The EMS signs are manually tested to check for defective LEDs and that the beacons are properly flashing. The various batteries and charge controller cabinets are also inspected at this time, as are the condition of solar panels (where employed). Finally, an audit and calibration of the system RPU and sensors is performed annually. Aside from these routine maintenance activities, the system does not present any specific maintenance challenges.

While the system is now operating in an expected manner following the rebuild, it was of interest to document any potential or scheduled improvements that might be made to the ICWS in the future. Future improvements would include an upgrade of the system controller to the Automated System Warning Controller (ASWC) presently being developed rather than using the

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[7] In discussing various aspects of the system with Susanville maintenance, it was indicated that a reconstruction of the roadway over Fredonyer Summit is planned for the near future. Such a reconstruction might provide an opportunity for investigation of more optimal sensor placement.

RPU as the system controller. In addition, it would be preferable to use cellular data connections to retrieve the speed data being recorded at each sign rather than using data cards that have to be downloaded/retrieved in the field. The sign controllers have a provision for cellular connection, so this upgrade would be relatively straightforward. The installation of additional sensors at strategic locations known to "freeze first" points will also be made. Since the target roadway segment is long, an additional RPU/data logger station will also be added. Use of the ASWC will allow aggregation of data from multiple data loggers for sign control, something not easily accomplished using the present controller.

At present, a new surface sensor with replaceable electronics is being tested. This sensor would allow for lab calibration as well as easy replacement. This would present an opportunity for reducing maintenance needs and time requirements. Some consideration has also been given to the use of on-contact pavement sensors (laser-based temp and surface condition). Such technology would also provide for simplified maintenance, calibration and repair compared to the in-pavement sensors used currently. Finally, it was thought that having the system connected to utility power with just a battery backup system would make maintenance easier.

Of course, one of the intentions of the Fredonyer Pass ICWS was to evaluate the effectiveness of a system which could be deployed in other locations facing similar icy surface issues. In line with this, it was of interest to learn from an ITS engineering viewpoint what design considerations should be made if similar systems are to be used elsewhere in the future. The first consideration, which was stated previously, is that the sensors for the system must be properly located to maximize their coverage/effectiveness in detecting conditions. Sensors should be placed in the locations of the roadway which are the first to freeze up and last to thaw out. In general, sensors should be generally located in the center of a lane, although in some cases, their placement at the edge of the roadway may be warranted. Winter maintenance personnel are familiar with the different micro climates and roadway conditions for the areas they maintain, and so they are a useful reference in understanding where sensors should be placed.

Future maintenance considerations for systems deployed at other sites include the need for annual system and sensor calibration and audits to ensure accuracy. While this is challenging from the standpoint of in-road sensors, which make checking surface temperature accuracies difficult to complete, it is necessary. Of course, alternative sensors/technologies could address or eliminate this issue. It is also important to select sensors that can be tested/calibrated easily and to employ data collection equipment in the system that uses open and easily programmed software. Also in relation to the puck sensors is the need for their locations need to be marked very conspicuously so that maintenance does not dig them out or inadvertently damage them during grinder operations. Sensors that have plug-in power as opposed to wiring connections would be advisable. Finally, it was stressed once again that a connection to utility power would be preferable.

Given that the system employs an RWIS station along with pavement sensor data to determine icy conditions, it was of interest to document whether the data being produced by the various components of the ICWS was being used by Caltrans personnel in Redding. While no personnel are known to specifically use the data in Redding, maintenance personnel in Susanville have, in past instances, used surface readings to determine the condition of deicer on the roadway. From an ITS engineer’s perspective, it has been a challenge to convince people that the data being delivered from the sensors is reliable.

In terms of the benefits of the system, the hope is that it has reduced accidents. Of course, prior to the results presented elsewhere in this report, that benefit was only generally identifiable through observation of crash trends. In terms of general challenges with the system, observations over several years of operation have indicated that the system has difficulty following road conditions during the early winter. There are occasions where ice may be present on one side of the roadway but not the other due to shading (ex. early morning). The use of additional sensors in such cases would address this issue. Also, employing data from supplemental sensors (ex. air temperature, precipitation, etc.) could possibly allow the system to compensate for times that roadway surface temperature and condition data is not sufficient in identifying potential icing conditions.

5.3. California Highway Patrol

A final perspective of interest to this work was the perceptions of the ICWS by California Highway patrol (CHP) personnel. CHP officers frequently pass over Fredonyer Pass during their patrols of Lassen Rt. 36, so it is reasonable to conclude that they have observed the ICWS in operation over time and developed perceptions and opinions of its functions and reliability. Consequently, the Susanville CHP Area Office was contacted to obtain feedback on the ICWS from the perspective of patrol officers. Officer Sam Glucklich provided feedback on various aspects of the system, which is summarized in the following sections.

Observations and perceptions of CHP regarding changes in speeds over the pass when the ICWS is on (particularly in vicinity of the targeted curves) were that drivers do seem to be slowing down. This is only perception though, and there has been no analysis performed by CHP (ex. review of ticket records) to verify whether it is in fact the case. One thought expressed is that when the weather is bad and someone is speeding, a driver is likely going to be in a crash regardless of warning signs, tickets, and so forth. In general, few tickets are issued during inclement conditions, so even without looking back at ticket records, it is likely that only a few tickets have been issued while the ICWS is on during a storm. It was believed that crashes over the pass have dropped in recent years, although again, no analysis of data has been performed to confirm this view. The thoughts of CHP on this drop were that it could be related to the ICWS, as well as manned chain control policies employed by Caltrans.

In general, the system appears to be accurate in indicating ice conditions. When the weather is bad, the system is on, which is expected. As far as conditions during clear and cold weather, the performance of the system is not something officers observe closely enough to determine its accuracy. The view of the system overall is that it is good to have a warning device for bad weather and road conditions overall. Aside from that, CHP officers have not had many thoughts on the system.

In addition to contacting CHP for feedback, commuter feedback from the general driver population traveling over the pass regarding perceptions of the system and its effectiveness in changing behaviors was sought. This was done through attempts to contact the group of drivers who travel over Fredonyer Pass on their way to work at the local prisons (specifically employees of the High Desert State Prison and the California Correctional Center). These facilities were contacted to seek volunteers to provide brief feedback on the system (experiences, perceptions, views). Unfortunately, no respondents were identified during the course of these contacts to answer questions about the ICWS from a driver perspective. As a result, driver feedback pertaining to the system was not obtained during the course of this work.

5.4. Chapter Conclusion

This chapter has provided feedback on the operations and perception of the ICWS from a number of viewpoints, including winter maintenance, ITS engineering staff and the California Highway Patrol. The following presents a summary of the information obtained from each of these groups.

From the perspective of winter maintenance, the ICWS is a good system with the visual aspects (electronic signage) it incorporates an improvement over typical static metal signage. Observations made over time have indicated that as the winter progresses, the system works better, with the easternmost system performing the best. Of course, there are still more improvements required of the system. Specifically, the use of additional pavement pucks for detection of conditions in multiple lanes was thought to hold the promise of improving system accuracy and reliability. The data produced by the ICWS (pavement temperature and condition, as well as general RWIS data) is not presently employed by maintenance forces for any activity, although the CCTV camera associated with the system's RWIS at the summit is used frequently to obtain visual information on present conditions. According to maintenance, field observations are relied on rather than ICWS data as they provide a wider picture of the conditions along the entire roadway. In general, the ICWS does not present much trouble to winter maintenance staff. Crews are careful when plowing snow not to hit the solar panels associated with the RWIS' of the system, and during general maintenance activities (i.e. summer work), care must be taken not to damage the wires and in-pavement sensors of the system when performing crack sealing and grinding operations.

Feedback provided by ITS engineering indicated that following the rebuilding of the ICWS, it is generally functioning as expected. However, observations over several years of operation have indicated that the system has difficulty identifying road conditions during the early winter. There are occasions where ice may be present on one side of the roadway but not the other due to shading (ex. early morning). The use of additional sensors in such cases would address this issue. Also, employing data from supplemental sensors (ex. air temperature, precipitation, etc.) could possibly allow the system to compensate for times that roadway surface temperature and condition data is not sufficient in identifying potential icing conditions. Normal maintenance was required to the ICWS following its rebuild, including visual inspection of surface sensors before each winter season (and cleaning as needed), replacing faulty sensors, testing EMS signs to check for defective LEDs and beacon operation, battery, charge controller cabinet and solar panel inspections, and audit/calibration of the system remote processing unit and sensors. Future improvements to the system would include an upgrade of the controller to the Automated System Warning Controller (ASWC), use of cellular data connections to retrieve speed data, and the installation of additional sensors at strategic locations. When considering similar systems for deployment elsewhere, these maintenance activities and identified improvements should be considered and incorporated. It is especially important to select roadway sensors that can be tested/calibrated easily and to employ data collection equipment in the system that uses open and easily programmed software. Additionally, the use of utility power for the system was strongly advised.

Finally, feedback provided by CHP indicated that drivers appear to be slowing down when the ICWS is on (particularly in vicinity of the targeted curves) This is only perception though, and there has been no analysis performed by CHP (ex. on ticket records) to verify whether it is in fact the case. It was also believed that crashes over the pass have dropped in recent years, although again, no analysis of data has been performed to confirm this view. The thoughts of CHP on this drop were that it could be related to the ICWS, as well as manned chain control policies employed by Caltrans. In general, the system appears to be accurate in indicating ice conditions. The view of the system overall is that it is good to have a warning device for motorists.

6. CONCLUSIONS AND RECOMMENDATIONS

The Fredonyer Pass Icy Curve Warning System was deployed by Caltrans to increase motorist vigilance and reduce the number of crashes occurring during icy pavement conditions in real-time. The ICWS consists of pavement sensors to detect icy conditions, in combination with dynamically activated signage to provide motorists with real-time warning when icy conditions are either imminent or present. The system is intended to alert motorists of icy conditions, eliciting a decrease in vehicle speeds during such conditions. Consequently, lower vehicle speeds are expected to translate to reduced crashes along the length of the curves which have presented safety challenges in the past.

While the system was initially installed during the summer of 2002, it did not reliably operate in the manner envisioned by Caltrans and required an extensive rebuild, which began during the spring of 2006. The rebuild and subsequent testing and validation of the system required a significant amount of time. As a result, the ICWS was not considered fully operational and reliable until the winter season of 2008-2009. The work presented in this report has evaluated the performance of the ICWS following the rebuild, focusing on the metrics of speed reduction under various conditions and safety performance through crash reduction. In addition, a review of literature pertaining to road condition warning systems was made, along with documentation of winter maintenance, ITS engineering and CHP perspectives of the ICWS.

Through the evaluations performed by this work, Caltrans should have a better understanding of how the Fredonyer Pass ICWS is meeting its primary objectives of reducing vehicle speeds during icy conditions and reducing crashes along the curves of interest and in their vicinity during those same icy conditions. The following sections provide a summary of the key findings produced through this work, as well as recommendations for future work that may be of interest as the system remains in operation.

6.1. Conclusions

6.1.1. Speed Analysis

The results of the statistical analysis of speed data suggest that the system is working as intended and that vehicle speeds are significantly lower. This was particularly true of speeds during clear, cold, and not dry weather conditions, when a driver would not necessarily expect to encounter ice. As one would expect, the system also appears to have contributed to lower vehicle speeds during weather events (i.e. snow) as well. Speed data were examined for statistically different differences overall (i.e. speeds when the system was on versus off differed by more than 0 mph), as well as at 3 mph and 5 mph (i.e. off versus on speeds differed from one another by at least these thresholds). T-tests were employed to perform the statistical evaluation.

As one would expect, mean speeds were significantly different by greater than 5 mph when the system was on versus off. In other words, when the system was turned on and providing a warning of ice conditions, vehicles traveled at much slower speeds Of course, this collective analysis told little about the performance of the system under different conditions, namely during the day and night, as well as during different weather. When speed data were examined by system state and time of day (day versus night) in combination, it was once again found that mean speeds were significantly different by greater than 5 mph. The general mean speed reductions observed ranged between 5.19 mph and 8.66 mph during the day and 5.72 mph and 8.30 mph during the night when the system was turned on.

When general wet weather (snow, rain, etc.) conditions were evaluated, it was found that mean speed reductions were significant by greater than 5 mph. During the day, mean speeds during wet weather fell between 6.20 mph and 10.73 mph when the system was on. At night, mean speeds during wet weather fell between 10.34 mph and 16.14 mph when the system was on. Such changes in vehicle speeds were expected during inclement weather, when poor visibility and the potential of reduced pavement friction combined to lead motorists to drive more slowly.

The real effectiveness of the Fredonyer ICWS on vehicle speeds was its impact during conditions when ice was present but unexpected by drivers. Such conditions, called clear, cold and not dry in this work, were times when snow melting or general water/ice pooling from the wet and cold environment of the curve locations may produce runoff across the roadway in the target curve and result in ice formation. When the base hypothesis that mean speeds differed from one another overall (0 mph) was examined, statistically significant differences were observed when the system was on versus off during clear, cold and not dry conditions during both the day and at night. These differences continued when the hypothesis of mean speed differences exceeding 3 mph was examined. However, only a limited number of mean speed differences were found to be statistically significant for speed differences of greater than 5 mph. Consequently, it appears that the ICWS is prompting motorists to reduce their speeds by less than or equal to 3 mph in conditions where icy roads are not necessarily expected. Whether this reduction that translates into long-term safety benefits (i.e. reduced crashes in the curves of interest), particularly during clear, cold and not dry conditions, remains to be seen. As the speed readings employed in this evaluation were collected at sign locations in advance of the curves of interest/concern targeted by the ICWS, the true changes in motorists speeds throughout the course of the curve remain unknown. It is possible that the observed changes in mean speeds reported here are translating into even more significant reductions by motorists as they enter and traverse each curve.

When examining different levels of manned chain control versus the system state and time of day, it appears that the greatest impact of the ICWS is when R-1 control is in effect. Under R-1, mean speeds at almost all sign locations fell by greater than 5 mph when the ICWS was on, a statistically significant change. This is encouraging, as roadway conditions under this level can be quite hazardous, and any additional speed reductions that might be achieved in addition to those produced by manned chain control are a benefit. The impact of the ICWS under Watch and R-1M conditions were limited and varied by the specific sign and time of day. While some statistically significant speed reductions were observed, these were cursory and generally less than 3 mph. While the differences between speeds when the ICWS was on and off could not be evaluated for the R-2 chain condition (the ICWS was always on), a general review when the system was on indicated that mean speeds during the day ranged from 33.85 mph to 38.72 mph and 35.48 to 38.22 mph at night.

In addition to evaluating the impacts of the ICWS on mean vehicle speeds, changes to 85th percentile speeds were also examined. As one would expect, this review yielded similar results to the analysis of mean speeds (note that no statistical analysis was performed on this data). Reductions of 85th percentile speeds were observed to varying extents for the system on versus off condition, day versus night, wet weather, and clear, cold and dry versus not dry conditions. Of specific interest once again was the performance of the system during clear, cold and not dry conditions. In such cases, observations from each sign location indicated that 85th percentile speeds fell; depending on the site, speeds fell between 1 mph to 5 mph during both the day and night. Once again, the significance of these drops should be taken in context with their collection location. Speed data was collected at the sign locations prior to the targeted curves. Consequently, reduced speeds prior to entering each set of curves may be indicative of greater speed reductions by motorists throughout the entire length of the curve.

6.1.2. Safety Analysis

In order to determine the safety effects of the ICWS, an observational before-after study using the Empirical Bayes technique was employed. This evaluation determined the effect of ICWS on crash frequencies. The results found that the deployment of the ICWS reduced the number of annual crashes by 18%, which corresponds to an Accident Modification Factor of 0.82. As no other changes occurred along the study segment (additional safety improvements, geometric changes, etc.), it is reasonable to attribute this observed safety improvement to the ICWS. Additionally, a crash rate method was used to investigate the effect of the ICWS on crash severities, with a focus on ice-related accidents. The results indicated that the ICWS has reduced crash severities. This reduction in severity is likely the result of vehicles traveling at slower speeds because of the ICWS in the event of a crash. As a result of reduced crash severities, the system was estimated to provide safety benefits of $1.7 million dollars per winter season during the after deployment study period (2008-2009, on account of time lag in crash data availability).

While the safety results are encouraging, caution is warranted in their interpretation. First, because of the nature of crash databases and data availability, combined with the timing of this evaluation, only 1 ½ years of after period data was available for analysis. While the Empirical Bayes approach employed in this work has been developed to accommodate cases of limited data, it would be advisable to revisit the safety performance of the Fredonyer ICWS at some point in the future when more years of crash data are available. Second, while the lack of any additional construction/safety improvements aside from the ICWS allowed for the assumption to be made that most of the observed safety improvement along the study segment could be attributed to the ICWS, future work should consider a more focused evaluation. Such an analysis would consider only the winter months and require the development of a specific Safety Performance Function.

6.1.3. System Perspectives

In addition to evaluating the performance of the system, feedback on the operation and perception of the ICWS was obtained from a number of viewpoints. These included winter maintenance, ITS engineering and the California Highway Patrol.

From the perspective of Susanville winter maintenance, the ICWS is an improvement over typical static metal signage. Observations made over time have indicated that as the winter progresses, the system works better. The use of additional pavement pucks for detection of conditions in multiple lanes could improve system accuracy and reliability. The data produced by the ICWS is not presently employed by maintenance forces for any activity, although the CCTV camera associated with the system’s RWIS at the summit is used frequently to obtain visual information on present conditions.

Feedback by ITS engineering indicated that following the rebuilding of the ICWS, it is generally functioning as expected. However, observations over several years of operation have indicated that the system has difficulty identifying road conditions during the early winter. The use of additional sensors in such cases would address this issue. Also, employing data from supplemental sensors (ex. air temperature, precipitation, etc.) could possibly allow the system to compensate for times that roadway surface temperature and condition data is not sufficient in identifying potential icing conditions. When considering similar systems for deployment elsewhere, it is especially important to select roadway sensors that can be tested/calibrated easily and to employ data collection equipment in the system that uses open and easily programmed software.

Finally, feedback provided by CHP indicated that drivers appear to be slowing down when the ICWS is on (particularly in vicinity of the targeted curves) This is only perception though, and there has been no analysis performed by CHP (ex. on ticket records) to verify whether it is in fact the case. It was also believed that crashes over the pass have dropped in recent years, although again, no analysis of data has been performed to confirm this view. The thoughts of CHP on this drop were that it could be related to the ICWS, as well as manned chain control policies employed by Caltrans. In general, the system appears to be accurate in indicating ice conditions. The view of the system overall is that it is good to have a warning device for motorists.

6.2. Challenges

During the course of this work, a couple of challenges were encountered. First, a lack of “after” period crash data limited the duration of the safety evaluation. This meant that only 1 ½ years of crash data following the rebuild of the system was available for the analysis. The lack of data stemmed from the lag which exists between the time that a crash occurs and when it becomes available as a record in a central database (in this case, TASAS). While the Empirical Bayes approach that was employed in completing the crash analysis is designed to accommodate cases such as this where limited data is available, the evaluation of a longer time period of crash data would obviously produce a more complete picture of the performance of the system.

A second challenge stemmed from the radar data collection equipment employed to collect vehicle speeds. The units, which were located at each EMS sign location, only collected vehicle speed, not the classification of that vehicle. While the collected data did provide for statistical evaluations regarding overall speed trends under a variety of conditions, it did not allow for an evaluation of the effects of the ICWS on the speeds of different vehicle types. Such an evaluation would be of interest as large vehicles (i.e. heavy trucks) are more likely to already be traveling slowly and may not produce as significant a change in speeds as passenger vehicles.

Finally, as stated in the prior paragraph, the speed collection units were located at the EMS signs prior to the curves that the ICWS was deployed to treat. Consequently, while data was available to examine vehicle behavior as motorists encountered the ICWS signage, the vehicle speed behaviors once inside the curves of interest remains unknown. While it is reasonable to assume that observed decreases in vehicle speeds that were measured prior to the curves would translate into equal or greater reductions as the curves were traversed, this remains only a hypothesis due to the lack of available data.

6.3. Recommendations

While not the focus of this work, agencies that may consider future ICWS deployments should be aware of a number of design and operational aspects that play a critical role in the success of such systems. Aside from obtaining reliable system components, it is essential to be sure that the system and sensors are calibrated correctly. Similarly, the algorithms employed in determining icy conditions must correctly process the data being received from different sensors and determine what actions are warranted based on current conditions. Finally, the recurrence of ice in certain locations is likely due in part to microclimate features; as such, it is essential to design, install and calibrate an ICWS specifically for the microclimate it is used in.

Based in part on the challenges discussed in the previous section, a number of recommendations for future work and monitoring are advisable. First, based on the short period of after crash data that was available for use in the crash analysis during this work, it would be advisable to revisit this analysis at a future date. A future evaluation would once again examine the effectiveness of the ICWS in reducing crashes, but would employ a longer duration of "after" period data, from 3 to 5 years or longer. The Empirical Bayes approach employed in this report could once again be used for that evaluation, examining crash data from throughout the year. Such work might also consider only winter months and employ the development of a specific Safety Performance Function. The development of such SPF's can be quite costly and time intensive, which is why such an approach was not employed in this work. However, through the development of an SPF specific for ICWS, the performance of an ICWS deployed elsewhere could be more easily evaluated. Regardless of the approach employed, the evaluation of crash trends over a longer period of time is necessary in order to understand the long term impacts and effectiveness of the ICWS. While initial results have indicated that it has had a positive impact on reducing crashes over Fredonyer Pass that does not necessarily mean that over a longer term this will hold true. By understanding the impacts of the ICWS on crashes, a better understanding can be developed regarding whether similar systems could be deployed elsewhere to address similar roadway ice issues.

Coincident with planning for future safety (and speed) evaluation, it is recommended that Caltrans District 2 maintain records of manned chain control levels from the present onward. These records can consist simply of saved .pdf files from the chain control report log. These files were used during the course of the analysis presented here, and will be sufficient for future work as well. The key is to save this data/files on an annual basis for future use.

Secondly, an evaluation of mean speed trends would also be advisable. Again, while the ICWS appears to be effective in producing a reduction in vehicle speeds under different conditions, particularly clear, cold and not dry conditions when ice isn't expected, the long term effectiveness of the system on speeds remains unclear. While this report evaluated data from two full winter seasons as well as the end of one partial season (spring 2009), it is possible that over a longer period of time, the system may lose some effectiveness, with vehicle speeds rising. Conversely, as the system remains deployed over a longer period, drivers may come to trust its indications of icy roads and produce further speed reductions in addition to those documented by this work. Without evaluating future years of speed data, long term effectiveness of the ICWS on speeds will remain unanswered.

When evaluating speed data in the future, it may also be advisable to collect speeds from the center of each targeted curve. The evaluation presented here only examined speed data from sign locations in advance of each curve. While the reviewed data provides a general sense of driver reactions to the ICWS message, it remains unknown whether, and to what extent, drivers slow down while passing through the targeted curves. Only through the collection of speed data at some point or points in each of the curves targeted by the ICWS can it be determined if drivers slow down to any significant extent (and, if so, by how much) as they pass through the curve. Of course, challenges may exist which make it more difficult to collect such data (ex. permits to place data collection equipment and/or run power to that equipment on Forest Service lands).

The speed data collected by radar during the course of this project was aggregate and did not classify vehicles by their type. Of course, on a mountain pass, the type of vehicle traveling up or down a grade will play a significant role in the speeds observed. For example, a heavy vehicle will travel much slower upgrade because of its weight when compared to a passenger car, regardless of the presence of curves and potential for ice. Similarly, a heavy vehicle will also travel more slowly downgrade in order to maintain control. The presence of such slow moving vehicles may lower overall average speeds when analyzed collectively with all other vehicles. While this was not viewed to be a problem in this analysis, given the large sample sizes of data examined, it would provide interesting information related to the behaviors of specific vehicle types. Consequently, if possible for future work, data should be collected by equipment which is capable of classifying and binning vehicles by type.

Finally, future work may consider obtaining feedback from the driver population traveling over the pass regarding perceptions of the system and its effectiveness in changing behaviors. This work attempted to reach out to drivers who travel over Fredonyer Pass on their way to work at the local prisons (specifically employees of the High Desert State Prison and the California Correctional Center). These facilities were contacted to seek volunteers to provide brief feedback on the system (experiences, perceptions, views). Unfortunately, no respondents were identified during the course of these contacts to answer questions about the ICWS from a driver perspective. Future work should again attempt to solicit feedback from these sources, as well as any others that may be identified. Past work related to the ICWS has also employed mailed surveys to residents in local communities, and this is another approach that might be considered.

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