Evaluation of the Fredonyer Pass Icy Curve Warning System

A Project Completed for 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 expected, 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. 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 during most seasons. However, statistically significant mean speed differences greater than 5 mph were observed less frequently overall. 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.

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 15%. 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 $1.03 million dollars per winter season during the after deployment study period (2008-2015). Overall, the safety evaluation results indicate that the system is having a positive impact on reducing all types of 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 surface sensors for detection of conditions in multiple lanes could improve system accuracy and reliability. The data produced by the ICWS are 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 provided by ITS engineering indicated that the primary benefit provided by the system is that it is viewed to be saving lives. The system, while complex and requiring a vigilant attitude toward maintenance, has helped to reduce crashes. Tasks associated with the system include battery maintenance, sensor monitoring and recalibration/replacement, data download (radar speeds), and sign checks for function and condition. While these activities require a lengthy trip to and from the site, they are critical in making sure that the system is working properly. Potential future improvements to the system that have been identified or recommended include migration of the power supply from solar panels to standard distribution via the local utility, and the possible use of out-of-pavement sensors to monitor pavement condition.

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 (e.g., on ticket records) to verify whether this is in fact the case There has not been a perceptible drop in crashes since the system became fully operational in 2009, at least from the perspective of CHP. 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 multiple curves and 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 and yellow flashing beacons to attract driver attention, all of which activate 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.

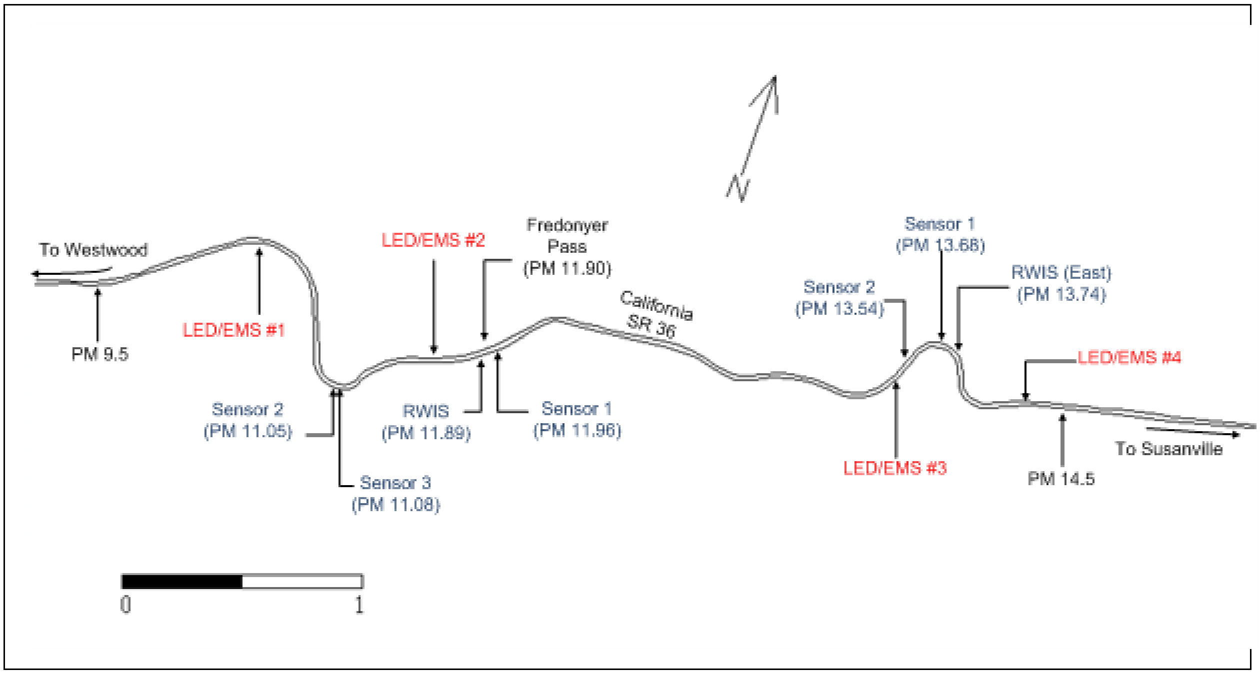

Figure 1-1 Schematic of Fredonyer Pass and ICWS system

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 long-term evaluation of its performance was of interest. 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 perspectives are of

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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.

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 the system of Caltrans winter maintenance and California Highway Patrol professionals in Susanville, 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 (i.e., 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. Ice Warning Systems and Research

2.1.1. Fredonyer Icy Curve Warning System

The initial evaluation of the Fredonyer ICWS, which was completed in 2011, focused on its short-term impacts on safety and operations, as well as maintenance experience with the system (1, 2, 3). [Note that the results presented in the following paragraphs are the results of that study and differ from those of the present study.] Given that the ICWS was not considered fully operational and reliable until the winter season of 2008-2009, this evaluation only considered crash data collected from July 1, 2008 to December 31, 2009 and speed data from the late-2008 through 2010-2011 winter seasons (a shorter period of crash data was used because of data lags in the Caltrans database). The work focused on the metrics of speed reduction under various conditions and safety performance through crash reduction. In addition, documentation of winter maintenance, ITS engineering and California Highway Patrol perspectives of the ICWS were made as part of the work.

The results of the statistical analysis of speed data indicated that the system was working as intended and that vehicle speeds were significantly lower. 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 system 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 could produce runoff across the roadway in the curves and result in ice formation. Mean speed differences exceeding 3 mph were observed during such conditions during both the day and at night at the four study sites. However, only a limited number of mean speed differences were found to be greater than 5 mph.

The safety impacts of the ICWS were evaluated using an observational before-after study employing the Empirical Bayes (EB) technique. The results found that the deployment of the ICWS reduced the number of annual crashes by 18 percent during the initial years following deployment (examining crashes up to the end of 2009). As no other changes occurred along the study segment (additional safety improvements, geometric changes, etc.), it was 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).

Finally, feedback from winter maintenance staff in 2011 indicated that the ICWS was an improvement over typical static metal signage and it appears to work better as the winter progresses. Feedback by ITS engineering staff (2011) indicated that following rebuilding, the ICWS was functioning as expected but the system has difficulty identifying road conditions during the early winter. Feedback from local California Highway Patrol indicated that drivers appeared to be slowing down when the ICWS is on (particularly in vicinity of the targeted curves). This was only perception though, and no analysis had been performed by CHP (e.g., on ticket records) to verify whether this was in fact the case at that time.

2.1.2. 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 (4). 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 performed 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 lower, while westbound average speeds were 8.4 mph lower. 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 by these administrative groups 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].

2.1.3. 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.

To address the conditions in Nugget Canyon, an ice warning system was installed in 2001 by the Wyoming Department of Transportation (WYDOT) (5). 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 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

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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.

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. 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.

2.1.4. Additional Ice-Related Warning Systems

Veneziano and Koon documented various types of automated safety warning systems deployed in the western U.S., including systems targeting icy pavement conditions (6). Aside from documenting systems discussed in other sections of this chapter, the work identified and summarized different aspects of systems that have not necessarily appeared elsewhere in literature. This included systems that provided ice warnings to drivers. The following paragraphs discuss the different systems documented by the work.

Similar to Fredonyer Summit, Caltrans deployed an ICWS at Spring Garden in Plumas County, California, on Plumas Highway 70 between postmiles 50.07 and 51.64 in 2008. The system is along a section of roadway that frequently experiences icy conditions due to snow melt and shading, detecting icy conditions and providing warning to motorists when ice is present. The system is comprised of pavement surface condition sensors, an RWIS, Changeable Message Signs (CMS), CCTV, controller, communications systems, and battery back-up equipment. When icy conditions are detected, the CMS located at each end of the segment are activated and flash a message of "CAUTION ICY ROAD." The system appears to have been effective at slowing drivers down when icy conditions are present based on observations; however, to date no crash or speed analysis had been performed for the site.

King County, Washington, has deployed a system to detect icy and slick pavement conditions and provide a warning to motorists. The system was activated during the spring of 2013 and is located along the South 277th Street/South 272nd Street corridor through Kent and Auburn, Washington. The corridor has steep grades, is curving and is shadowed by a good deal of vegetation, resulting in the potential for ice-related crashes. The system addresses these conditions by providing motorists with warning via messages stating "Watch for Ice" posted to extinguishable message signs along the corridor. No crash or speed analysis had been performed for the system to date.

The Nevada Department of Transportation deployed an ice warning system for travelers at the Carlin tunnels on I-80 in 1985 and the system was still active as of 2014. The intent of the system is to warn drivers of the presence of ice within the tunnel. The system uses pavement surface sensors and noninvasive infrared grip sensors to detect ice presence, with the information from these sensors used to activate flashing beacons on static metal warning signs. No formal evaluations of the system have been made, but observations by staff indicated that it is moderately effective in detecting ice and providing warning.

The Wyoming DOT deployed an ice warning system for a bridge site at Piney Creek on I-90 in 2006 to address a high number of ice-related bridge crashes. The system uses pavement surface sensors on the bridge deck to detect pavement conditions and air temperature sensors to collect atmospheric conditions. Based on the data from these sensors, if ice formation is possible based on condition thresholds, the system controller activates the flashing beacons on static metal warning signs located at either end of the bridges crossing the creek. No formal evaluation of the system has been performed, but according to DOT staff the system seems to have addressed crashes.

Finally, the Utah DOT deployed an ice detection and warning system for a bridge site at Fish Creek on I-70 in 2013. The location had experienced a high number of crashes as attributed to “ice on bridge deck.” The system uses an RWIS station to monitor for snow and ice presence on the west end of the bridge deck. When the system controller determines snow or ice are present (note that a certain threshold is not employed), a warning stating “Icy Bridge Ahead” is posted to two CMS signs on the roadside. No formal evaluation of the system was performed.

2.1.5. Washington State Ice Warning Evaluation

Carson and Mannering evaluated the effect of ice warning signs on ice-accident frequencies and severities in Washington State (7). While the signs the researchers examined were static (standard diamond-shaped) and did not incorporate any ITS components (e.g., 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 (e.g., 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 and 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.

2.2. Additional Weather-Related Systems

2.2.1. Idaho Storm Warning Project

The Idaho Storm Warning Project was initiated in 1993 (and remains active) 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 (8). 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 (8).

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.

2.2.2. 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) (9).

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 the system was calibrated; data was collected from Phase II but eliminated from the system evaluation because it was deemed unreliable due to sensor issues. 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. The standard deviation decreased from Phase I to Phase III by 22 percent.

There was a difference in the reduction of standard deviation of 35 percent for moderate fog conditions, but no reduction in dense fog. 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.

2.2.3. 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 (10). 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 were 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 no change 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 (11).

Through a separate study using a series of three questionnaires, the effectiveness of the system was evaluated (12). 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 (12).

2.2.4. 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 (13). 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 they 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.

2.3. 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).

3. ANALYSIS OF SPEED DATA

This chapter presents the results of various evaluations for the Fredonyer ICWS of the differences in vehicle speeds based on various sets of conditions. These included the system state (on versus off), day versus night, weather conditions, with a focus on clear, cold and dry weather, and manned chain control[3]. The first two conditions represent a high level evaluation, while the latter weather and road surface evaluations represent an opportunity to determine if 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 during clear, cold and dry conditions are statistically different from other 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 portion of the evaluation, as well as the results of the different analyses 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.

A word of guidance is provided to the reader prior to reviewing this chapter. The data and trends laid out in the following text are meant to prove a supplemental understanding of how the ICWS is performing, in this, by eliciting a change in driver behavior through a lowering of observed vehicle speeds when the warning message is displayed. However, the data available for completing the analysis, such as a precise understanding of weather conditions at a sign location at the moment a speed reading was collected were extrapolated from nearby RWIS stations and subject to error. The true measure of effectiveness of the ICWS, a reduction in crashes, is discussed in the following chapter, and the reader should bear in mind that the discussion of speed data presented here is intended to provide a secondary, albeit imperfect, measure of the impacts that the system is having on drivers.

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, October 1, 2010 – April 15, 2011, October 1, 2011 – April 15, 2012, October 1, 2012 – April 15, 2013, October 1, 2013 – April 15, 2014, and October 1, 2014 – April 15, 2015. 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

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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, 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.

comma delimited file to a memory unit at each location. Speed data was downloaded in the field from each unit approximately once per month by Caltrans staff and archived for later use. 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 as they approach the signs and prior to entering each curve (signs only displaying a message when the system is on), it is likely that most local motorists would already be slowing down after seeing an ice warning message displayed from an advanced distance. On-site observations by Caltrans staff have been that many drivers are slowing as the pass under the signs, which would be missed by the radar units and potentially underestimate the significance of the speed reductions being achieved. The data used in this work represents the initial speed behaviors of motorists as they begin to enter each curve. It is reasonable to assume that vehicles are traveling slower throughout the length of the curve if they are observed to slow prior to entering the curves when the system is turned on. However, the limitation to this work 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. This was the result of infrastructure limitations to support additional radar units.

Prior to beginning the statistical analysis, data cleanup was required. Although data was collected between all of the dates listed, gaps in speed measurements did occur on occasion due to power issues, resulting in missing data at different locations for some time periods. In most cases, these were of brief nature; however, all data for Sign 3 during the 2012 – 2013 season was viewed as corrupt and excluded from the analysis. This was due to the season beginning with an incorrect date and timestamp (default value of November 1, 2005), which was the result of a power failure and radar system reset. This was followed by numerous power failures and resets, which made it impossible to determine a proper date and timestamp offset to correct and bring the data into the present year. The omission of this one season of data from one site was not expected to have a significant impact based on the availability of remaining seasons of data for analysis.

Other power failures and system resets were also observed on occasions at all signs, but these were of brief duration and on a correctable scale. For example, 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, with an appropriate time/date shift employed.

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 in such cases 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.

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:

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

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 initial speed data comparison performed examined whether vehicle speeds were significantly different when the ICWS was on versus when it was off. Note that time of day (day versus night), weather conditions (wet, clear, cold and dry, etc.), and the level of manned chain control are not taken into consideration, as these different conditions will be evaluated through tests discussed later in this chapter. The results of the evaluation performed for system on versus off mean speeds 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).

In examining the results of the mean speed tests, it is immediately evident that in general mean speeds were significantly different when the system was on versus off, as evidenced by the results of the test conducted on a speed difference of zero miles per hour. When examining the test results for speed differences of 3 miles per hour, speeds were found to be significantly lower when the system was on versus off in most cases. The exceptions to this were Sign 1 (2011-2012) and Sign 4 (2011 – 2012, 2013 – 2014). Finally, results of evaluations on speed differences of 5 miles per hour produced mixed results. During the initial years following system deployment (Spring 2009 – Spring 2011), a number of cases were observed where significant mean speed differences of 5 miles per hour had been observed. This was less of the case from the Fall of 2011 onward, with only the 2012 – 2013 season producing statistically significant speed changes of 5 miles per hour. However, the results of the system being on versus off do not indicate whether the system is meeting the objective of eliciting speed changes during clear, cold and not dry conditions, so these results should be considered accordingly.

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

March 12, 2009 - April 15, 2009

Location	Condition	Sample Size	Mean Speed	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	27404	56.53	0.79	**6.14**	-17.14	-32.66
	On	1556	55.74				
Sign 2	Off	30313	56.95	4.49	**18.57**	**6.16**	-2.11
	On	994	52.46				
Sign 3	Off	30336	55.46	6.51	**19.44**	**10.48**	**4.51**
	On	511	48.95				
Sign 4	Off	25145	58.39	5.75	**10.47**	**4.99**	1.35
	On	202	52.64				

October 1, 2009 - March 31, 2010

Location	Condition	Sample Size	Mean Speed	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	69298	55.83	5.61	**147.17**	**68.44**	**15.96**
	On	53042	50.22				
Sign 2	Off	71438	55.93	8.08	**123.73**	**77.80**	**47.18**
	On	29797	47.85				
Sign 3	Off	103086	54.29	8.17	**194.52**	**123.11**	**75.50**
	On	41022	46.12				
Sign 4	Off	108242	57.59	6.20	**143.05**	**73.82**	**27.67**
	On	39472	51.39				

October 1, 2010 - April 15, 2011

Location	Condition	Sample Size	Mean Speed	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	69900	55.38	5.60	**141.76**	**65.71**	**15.02**
	On	52177	49.78				
Sign 2	Off	74189	55.60	7.93	**150.83**	**93.88**	**55.84**
	On	42626	47.67				
Sign 3	Off	98460	53.76	8.13	**189.21**	**119.41**	**72.88**
	On	40650	45.63				
Sign 4	Off	104478	57.03	6.41	**146.02**	**77.72**	**32.19**
	On	39745	50.62				

BOLD indicates significance

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

Location	Condition	Sample Size	Mean Speed	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)
October 1, 2011 - April 15, 2012							
Sign 1	Off	46315	56.08	4.29	**79.16**	**23.87**	-12.97
	On	34356	51.79				
Sign 2	Off	75294	55.41	4.00	**76.42**	**19.13**	-19.06
	On	47890	51.41				
Sign 3	Off	108970	54.61	4.62	**125.83**	**44.18**	-10.25
	On	47610	49.99				
Sign 4	Off	108883	57.38	2.74	**76.09**	-7.18	-62.71
	On	43141	54.64				
October 1, 2012 - April 15, 2013							
Location	**Condition**	**Sample Size**	**Mean Speed**	**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	43552	55.64	6.73	**63.97**	**35.47**	**16.47**
	On	7790	48.91				
Sign 2	Off	57049	54.92	7.07	**105.89**	**60.93**	**30.96**
	On	28474	47.85				
Sign 3	Off	Data unavailable for this site					
	On						
Sign 4	Off	75453	57.04	6.05	**90.47**	**45.71**	**15.87**
	On	16090	50.99				
October 1, 2013 - April 15, 2014							
Location	**Condition**	**Sample Size**	**Mean Speed**	**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	57997	55.80	2.61	**57.98**	-8.53	-52.88
	On	32055	53.19				
Sign 2	Off	54283	55.93	4.85	**83.27**	**31.71**	-2.65
	On	38498	51.08				
Sign 3	Off	114405	50.30	5.13	**145.75**	**60.54**	**3.74**
	On	58188	45.17				
Sign 4	Off	102446	57.51	2.80	**82.19**	-5.88	-64.60
	On	40007	54.71				
October 1, 2014 - April 15, 2015							
Location	**Condition**	**Sample Size**	**Mean Speed**	**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	90563	56.42	3.20	**67.32**	**4.27**	-37.76
	On	25392	53.22				
Sign 2	Off	71595	56.12	8.65	**92.32**	**60.30**	**38.95**
	On	14499	47.47				
Sign 3	Off	102090	54.50	4.77	**72.07**	**26.78**	-3.41
	On	10095	49.73				
Sign 4	Off	142567	57.67	4.20	**62.02**	**17.75**	-11.76
	On	13801	53.47				
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 difference in speeds occurred when the system was on versus off based on the time of day. In order to determine day versus night conditions, sunrise and sunset times for Fredonyer Summit were determined using an Excel add-in function created by the National Oceanic and Atmospheric Administration (NOAA) (14). The function calculated sunrise and sunset times for the location based on latitude, longitude, date, and time zone. While this approach did not account for dusk and dawn periods where some limited daylight existed, it did serve to approximate daylight versus night 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.

Similar to the results from the comparisons of speeds between system on and off state, the state of the system broken down by day and night showed that speeds were significantly different at the zero mile per hour level. This was expected, as the system being on and providing a warning, both during the day and at night, was expected to produce some detectable lowering in speeds, and the results for the zero mile per hour category confirm this. At the 3 mile per hour level, speeds were found to be statistically lower at both day and at night, at all sites over the study period. The only exceptions to this were Sign 1 during the day in the spring of 2009 and at day and night in 2013 – 2014, and Sign 4 during the day in 2011 – 2012 and 2013 – 2014. These signs are located at the opposite ends of the corridor, so it is not surprising that these seasons did not necessarily produce significant drops of even 3 miles per hour, given that many vehicles are still travelling at higher speeds at these particular points.

Speed differences at the 5 mile per hour level produced mixed results. During the initial years following system deployment, statistically significant differences in speeds were observed both during the day and at night. However, after the Spring of 2011, speeds have not generally been significant at the 5 mile per hour level, aside from the 2012 – 2013 season. This may be indicative that the system has some influence on lowering vehicle speeds by a small amount as the curves are approached, but that reduction is not reaching 5 miles per hour. Again, this particular portion of the analysis does not consider speed changes specifically during clear, cold and not dry conditions, so these results should be considered accordingly.

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

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)
Sign 1	Off-Night	4609	55.69	0.25	0.87	-9.57	-16.53
	On-Night	522	55.44				
	Off-Day	22795	56.70	0.80	**6.02**	-16.52	-31.56
	On-Day	1034	55.90				
Sign 2	Off-Night	5587	55.65	5.81	**12.28**	**5.93**	1.70
	On-Night	300	49.84				
	Off-Day	24726	57.24	3.65	**13.57**	**2.42**	-5.01
	On-Day	694	53.59				
Sign 3	Off-Night	5191	54.32	4.57	**7.62**	**2.60**	-0.73
	On-Night	216	49.75				
	Off-Day	25145	55.70	7.34	**19.29**	**11.40**	6.14
	On-Day	295	48.36				
Sign 4	Off-Night	4831	57.15	5.32	**6.51 (1)**	**2.83 (1)**	0.38 (1)
	On-Night	93	51.83				
	Off-Day	20314	58.68	5.35	**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	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	15850	55.61	6.20	**85.49**	**44.15**	**16.59**
	On-Night	19568	49.40				
	Off-Day	53448	55.90	5.20	**115.23**	**48.69**	**4.34**
	On-Day	33474	50.70				
Sign 2	Off-Night	18556	55.25	8.43	**76.02**	**48.94**	**30.90**
	On-Night	10777	46.82				
	Off-Day	52882	56.17	7.74	**95.46**	**58.45**	**33.78**
	On-Day	19020	48.43				
Sign 3	Off-Night	28925	53.78	7.82	**102.64**	**63.23**	**36.96**
	On-Night	14392	45.96				
	Off-Day	74161	54.49	8.30	**164.42**	**104.91**	**65.23**
	On-Day	26630	46.19				
Sign 4	Off-Night	36607	56.86	5.84	**94.33**	**45.85**	**13.53**
	On-Night	20128	51.02				
	Off-Day	71635	57.98	6.19	**100.33**	**51.65**	**19.19**
	On-Day	19344	51.79				

BOLD indicates significance

(1) Critical value = 1.98

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

October 1, 2010 - April 15, 2011

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	12367	54.70	5.72	**69.48**	**33.01**	**8.69**
	On-Night	18885	48.98				
	Off-Day	57533	55.53	5.29	**115.44**	**49.88**	**6.18**
	On-Day	33292	50.24				
Sign 2	Off-Night	15846	55.36	8.66	**95.09**	**62.16**	**40.20**
	On-Night	17960	46.70				
	Off-Day	58343	55.67	7.30	**109.65**	**64.60**	**34.56**
	On-Day	24666	48.37				
Sign 3	Off-Night	21042	52.85	7.64	**102.54**	**62.28**	**35.44**
	On-Night	17805	45.21				
	Off-Day	77418	54.01	8.05	**148.75**	**93.33**	**56.38**
	On-Day	22845	45.96				
Sign 4	Off-Night	30586	56.61	6.37	**94.96**	**50.24**	**20.42**
	On-Night	19331	50.24				
	Off-Day	73904	57.21	6.23	**104.66**	**54.27**	**20.68**
	On-Day	20414	50.98				

BOLD indicates significance

(1) Critical value = 1.98

October 1, 2011 - April 15, 2012

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	4866	53.57	6.80	**38.84**	**21.71**	**10.29**
	On-Night	7760	46.77				
	Off-Day	40134	56.38	3.14	**60.16**	**2.81**	-35.36
	On-Day	26148	53.24				
Sign 2	Off-Night	13027	53.94	4.53	**42.68**	**14.46**	-4.35
	On-Night	14971	49.41				
	Off-Day	60267	55.77	3.40	**56.07**	**6.69**	-26.22
	On-Day	32529	52.37				
Sign 3	Off-Night	23120	53.74	4.30	**71.48**	**21.64**	-11.59
	On-Night	25460	49.44				
	Off-Day	85056	54.85	4.12	**83.77**	**22.69**	-18.33
	On-Day	21821	50.73				
Sign 4	Off-Night	18551	56.11	2.10	**35.03**	-14.95	-48.22
	On-Night	21522	54.01				
	Off-Day	88598	57.63	2.38	**49.00**	-12.73	-53.88
	On-Day	21364	55.25				

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

October 1, 2011 - April 15, 2012

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	4866	53.57	6.80	**38.84**	**21.71**	**10.29**
	On-Night	7760	46.77				
	Off-Day	40134	56.38	3.14	**60.16**	**2.81**	-35.36
	On-Day	26148	53.24				
Sign 2	Off-Night	13027	53.94	4.53	**42.68**	**14.46**	-4.35
	On-Night	14971	49.41				
	Off-Day	60267	55.77	3.40	**56.07**	**6.69**	-26.22
	On-Day	32529	52.37				
Sign 3	Off-Night	23120	53.74	4.30	**71.48**	**21.64**	-11.59
	On-Night	25460	49.44				
	Off-Day	85056	54.85	4.12	**83.77**	**22.69**	-18.33
	On-Day	21821	50.73				
Sign 4	Off-Night	18551	56.11	2.10	**35.03**	-14.95	-48.22
	On-Night	21522	54.01				
	Off-Day	88598	57.63	2.38	**49.00**	-12.73	-53.88
	On-Day	21364	55.25				

October 1, 2012 - April 15, 2013

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	12935	54.66	7.75	**49.23**	**30.17**	**17.46**
	On-Night	4212	46.91				
	Off-Day	30072	56.06	4.83	**36.41**	**13.70**	-1.43
	On-Day	3565	51.23				
Sign 2	Off-Night	1853	53.29	7.73	**60.63**	**37.10**	**21.42**
	On-Night	9955	45.56				
	Off-Day	44662	55.34	6.27	**78.52**	**40.97**	**15.92**
	On-Day	18283	49.07				
Sign 3	Off-Night	Data unavailable for this site					
	On-Night						
	Off-Day						
	On-Day						
Sign 4	Off-Night	15979	56.06	5.65	**52.19**	**24.51**	**6.04**
	On-Night	6976	50.41				
	Off-Day	58711	57.32	6.06	**64.26**	**32.46**	**11.26**
	On-Day	7893	51.26				

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

October 1, 2014 - April 15, 2015							
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	20445	55.74	2.79	**36.61**	-2.73	-28.97
	On-Night	13623	52.95				
	Off-Day	58487	56.82	3.07	**46.44**	**1.02**	-29.25
	On-Day	11002	53.75				
Sign 2	Off-Night	9552	54.46	8.73	**53.14**	**34.88**	**22.71**
	On-Night	6040	45.73				
	Off-Day	53182	57.08	8.18	**67.02**	**42.44**	**26.06**
	On-Day	8134	48.90				
Sign 3	Off-Night	25452	53.65	4.07	**32.70**	**8.60**	-7.47
	On-Night	3223	49.58				
	Off-Day	69169	54.78	4.98	**63.65**	**25.33**	-0.21
	On-Day	6872	49.80				
Sign 4	Off-Night	29163	56.55	3.27	**34.50**	**2.92**	-18.13
	On-Night	7363	53.28				
	Off-Day	99291	58.09	3.67	**37.15**	**6.85**	-13.35
	On-Day	5717	54.42				
BOLD indicates significance							

3.3.3. Weather Conditions

One of the primary objectives of the 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. In such conditions, a driver is likely to travel at a higher speed, 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, it is expected that significantly different (lower) vehicle speeds compared to times when then system was off would be observed. If this is indeed the case, it may be concluded that the ICWS is likely performing its intended purpose.

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 Caltrans ScanWeb. Two types of data were obtained, pavement surface temperature and condition (dry, icy, etc.) data, as well as general weather data. All of the readings obtained for these elements had a timestamp associated with them, allowing conditions at that specific time to be matched up with individual speed readings from each site. Two lookup tables were created in Excel and populated with this data; one with precipitation data and the second with surface temperature data. As the ICWS directly employed information regarding surface wetness as part of the algorithm to turn the warning messages on and off, the sign status element was not included as a lookup variable.

Next, each individual speed record was matched to the weather conditions that were present at the same time in the lookup table. Each of the different condition variables associated with the individual speed reading were then classified by their respective scenario (see Table 3-3), which included a) wet, b) clear, cold and dry, and c) 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 throughout the entire study period.

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. At the zero mile per hour level, results of the t-test were statistically significant across all study seasons (with the exception of Sign 1 in the Spring of 2009). This indicates that drivers are slowing down in advance of the curves when the signs are displaying a warning under precipitation conditions.

In order to determine the magnitude of speed reductions that were occurring, t-tests at the 3 mile per hour threshold were first performed. The results of these tests were once again all statistically significant (aside from most signs and conditions in the Spring of 2009), indicating that drivers were slowing down by at least 3 miles per hour in advance of the curves during precipitation conditions when a warning is displayed.

Next, t-tests at the 5 mile per hour level were conducted to determine whether speed reductions of this magnitude had been produced. In examining the results of Table 3-4, an interesting trend is observed. Between October, 2009, and April 2013, the observed speed reductions were statistically significant at the 5 mile per hour level. However, during the 2013-2014 season, fewer test results, depending on the sign, were statistically significant. This trend appears to have reversed during the 2014-2015 season, with speed changes and their significance matching those of earlier years.

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 (1)	-0.07 (1)
		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 (2)**	**6.14 (2)**	**5.18 (2)**
		On-Night	12	39.33				
		Off-Day	10143	55.65	9.36	**17.85 (3)**	**12.13 (3)**	**8.31 (3)**
		On-Day	140	46.29				
	Sign 4	Off-Night	440	56.64	17.31	**10.02 (4)**	**8.28 (4)**	**7.12 (4)**
		On-Night	6	39.33				
		Off-Day	9006	58.52	4.60	**5.14 (1)**	1.79 (1)	-0.44 (1)
		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

(1) Critical value = 1.99 (2) Critical value = 2.20

(3) Critical value = 1.97 (4) Critical value = 2.57

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

October 1, 2010 - April 15, 2011

	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				

October 1, 2011 - April 15, 2012

	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	4135	53.24	12.39	**47.50**	**35.99**	**28.31**
		On-Night	1834	40.85				
		Off-Day	38574	56.38	7.67	**63.31**	**38.56**	**22.06**
		On-Day	5461	48.71				
	Sign 2	Off-Night	10947	53.75	12.90	**54.56**	**41.87**	**33.42**
		On-Night	1834	40.85				
		Off-Day	57578	55.81	8.97	**62.85**	**41.83**	**27.81**
		On-Day	5344	46.84				
	Sign 3	Off-Night	16111	53.72	8.07	**49.89**	**31.35**	**18.99**
		On-Night	3014	45.65				
		Off-Day	81118	54.84	7.06	**64.21**	**36.94**	**18.76**
		On-Day	5471	47.78				
	Sign 4	Off-Night	17307	56.12	8.74	**43.43**	**28.53**	**18.60**
		On-Night	1949	47.38				
		Off-Day	87316	57.63	4.99	**45.90**	**18.29**	-0.11
		On-Day	5708	52.64				

BOLD indicates significance

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

October 1, 2012 - April 15, 2013

	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	10000	54.70	11.07	**35.22**	**25.68**	**19.32**
		On-Night	632	43.63				
		Off-Day	27018	56.09	4.41	**20.92**	**6.68**	-2.80
		On-Day	1322	51.68				
	Sign 2	Off-Night	9148	53.05	13.25	**44.66**	**34.55**	**27.81**
		On-Night	828	39.80				
		Off-Day	27018	56.09	9.76	**64.80**	**44.88**	**31.61**
		On-Day	4896	46.33				
	Sign 3	Off-Night	Data unavailable for this site					
		On-Night						
		Off-Day						
		On-Day						
	Sign 4	Off-Night	12587	56.05	9.57	**41.59**	**28.55**	**19.86**
		On-Night	1489	46.48				
		Off-Day	54480	57.32	6.93	**46.11**	**26.14**	**12.83**
		On-Day	3521	50.39				

October 1, 2013 - April 15, 2014

	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	12353	52.89	4.76	**19.21**	**7.10**	-0.96
		On-Night	1094	48.13				
		Off-Day	34022	56.54	3.73	**24.38**	**4.77**	-8.29
		On-Day	2168	52.81				
	Sign 2	Off-Night	6913	53.41	4.31	**10.55**	**3.19**	-1.71
		On-Night	546	49.10				
		Off-Day	35753	56.31	6.79	**41.38**	**23.10**	**10.91**
		On-Day	3665	49.52				
	Sign 3	Off-Night	29477	50.07	4.68	**73.30**	**26.25**	-5.10
		On-Night	18840	45.39				
		Off-Day	55248	50.58	5.40	**77.52**	**34.45**	**5.74**
		On-Day	12807	45.18				
	Sign 4	Off-Night	14218	56.26	6.34	**24.57**	**12.96**	**5.22**
		On-Night	1051	49.92				
		Off-Day	77789	57.76	3.75	**39.92**	**7.96**	-13.34
		On-Day	5775	54.01				

BOLD indicates significance

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

October 1, 2014 - April 15, 2015								
	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	18526	55.66	4.78	**32.45**	**12.09**	-1.48
		On-Night	3763	50.88				
		Off-Day	48590	56.85	7.22	**33.05**	**19.32**	**10.16**
		On-Day	1775	49.63				
	Sign 2	Off-Night	9266	54.47	7.97	**30.07**	**18.74**	**11.19**
		On-Night	2142	46.50				
		Off-Day	52771	57.13	7.77	**50.38**	**30.93**	**17.96**
		On-Day	5084	49.36				
	Sign 3	Off-Night	21097	53.75	6.73	**18.24**	**10.11**	**4.69**
		On-Night	484	47.02				
		Off-Day	68143	54.80	5.20	**59.87**	**25.33**	**2.30**
		On-Day	5397	49.60				
	Sign 4	Off-Night	26763	56.58	9.35	**31.13**	**21.25**	**14.55**
		On-Night	1036	47.23				
		Off-Day	97172	58.10	5.12	**32.03**	**13.25**	0.73
		On-Day	2746	52.98				

BOLD indicates significance

In order to better understand the true effect the ICWS may have on speeds for the primary conditions of concern, that of clear, cold and not dry pavement, an examination of speed behaviors when inclement conditions (that is, during precipitation events) were not present was made. Again, these were the conditions where a motorist would not expect to encounter ice and where, if the warning posted by the ICWS was heeded, speeds for the on versus off system state should be significantly different. Significant drops in vehicle speeds should be observed in this portion of the analysis if the system is meeting its objective effectively.

Table 3-5 presents the results of t-tests performed on speed changes between clear, cold and dry and not dry conditions. As was the case for all other scenarios examined so far, statistically significant reductions in speeds were observed in clear, cold and not dry conditions for both the day and at night at the zero mile per hour level. In other words, drivers were slowing down when the system displayed a warning message during clear, cold and not dry conditions. The extent of that speed reduction was variable though. At the 3 mile per hour level, most t-tests were statistically significant, both during the day and at night. However, there were cases, particularly during the day, where the test results were not significant on account of the observed speed reductions being less than 3 miles per hour. This was particularly true for day and night test results for the 2014-2015 season.

Test results at the 5 mile per hour level indicated that only a handful of speed reductions, mainly at night, were statistically significant. There was no clear pattern in terms of one or more signs producing significant reductions at this level. Rather, statistical significance varied by sign and by year. Collectively, the test results indicate that speed reductions were generally less than 5 miles per hour as drivers approached the curves.

Collectively, the results for clear, cold and not dry conditions indicate that the ICWS is achieving its purpose of eliciting a speed reduction as drivers approach the curves. Only one anomaly was noted, that being at Sign 4 during the spring of 2009 time period, where mean speeds rose by 6.36 mph when the signs were turned on at night. However, the data collection time period for this initial season was quite short, and that likely resulted in a limited sample size that skewed this particular case. Overall, that reduction is on the order of 3 miles per hour. However, the results point toward the potential for greater speed reductions on the part of vehicles as they travel into and through the curves beyond the warning sign locations. The test results indicating speed reductions of 3 miles per hour underscore that the ICWS appears to be meeting its intended purpose; that is, drivers are being made aware of the potential for encountering ice ahead when it would not be expected and are beginning to reduce their speeds as they approach the curves. The extent of that speed reduction once entering and travelling through the curves is not known, although additional radar sensors will be placed during a pavement rehabilitation project in 2017 which will allow this potential reduction to be identified in a future evaluation. Measured speed reductions made prior to entering the curves and field observations made by Caltrans staff of additional slowing at the signs indicate that the system is producing lower speeds and safer driving once entering the curves.

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 (1)	-2.52 (1)
	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 (2)**	**2.50 (2)**	1.52 (2)
	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 (2)**	**8.63 (2)**	**6.48 (2)**
	Day	Clear, cold and not dry / ON	40	44.37				
	Night	Clear, cold and dry / OFF	12	55.41	3.96	-0.41 (3)	-1.62 (3)	-2.43 (3)
	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 (4)**	**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 (5)	-2.67 (5)
	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 (1.96)	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

(1) Critical value = 1.98 (2) Critical value = 2.01

(3) Critical value = 2.14 (4) Critical value = 2.03

(5) Critical value = 2.57

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				

October 1, 2011 - April 15, 2012

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	56.52	2.09	**11.71**	-5.08	-16.27
	Day	Clear, cold and not dry / ON	20687	54.43				
	Night	Clear, cold and dry / OFF	731	55.46	6.87	**25.02**	**14.09**	**6.81**
	Night	Clear, cold and not dry / ON	5926	48.59				
Sign 2	Day	Clear, cold and dry / OFF	2689	55.16	1.70	**9.95**	-7.52	-19.17
	Day	Clear, cold and not dry / ON	27185	53.46				
	Night	Clear, cold and dry / OFF	2080	54.98	5.57	**30.44**	**14.06**	**3.14**
	Night	Clear, cold and not dry / ON	14971	49.41				
Sign 3	Day	Clear, cold and dry / OFF	3639	55.05	3.32	**32.86**	**3.18**	-16.59
	Day	Clear, cold and not dry / ON	16344	51.73				
	Night	Clear, cold and dry / OFF	6603	53.77	3.74	**44.82**	**8.88**	-15.04
	Night	Clear, cold and not dry / ON	22172	50.03				
Sign 4	Day	Clear, cold and dry / OFF	1037	57.46	1.27	**8.47**	-11.61	-25.01
	Day	Clear, cold and not dry / ON	15575	56.19				
	Night	Clear, cold and dry / OFF	1214	55.92	1.25	**8.09**	-11.38	-24.37
	Night	Clear, cold and not dry / ON	19496	54.67				

BOLD indicates significance

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

October 1, 2012 - April 15, 2013

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	3054	55.78	4.79	**24.25**	**9.05**	-1.07
	Day	Clear, cold and not dry / ON	2243	50.99				
	Night	Clear, cold and dry / OFF	2935	54.53	7.04	**33.31**	**19.12**	**9.66**
	Night	Clear, cold and not dry / ON	3580	47.49				
Sign 2	Day	Clear, cold and dry / OFF	3054	55.78	5.71	**42.28**	**20.07**	**5.27**
	Day	Clear, cold and not dry / ON	13387	50.07				
	Night	Clear, cold and dry / OFF	2705	54.08	8.00	**41.54**	**25.98**	**15.60**
	Night	Clear, cold and not dry / ON	9127	46.08				
Sign 3	Day	Clear, cold and dry / OFF	Data unavailable for this site					
	Day	Clear, cold and not dry / ON						
	Night	Clear, cold and dry / OFF						
	Night	Clear, cold and not dry / ON						
Sign 4	Day	Clear, cold and dry / OFF	3614	57.31	5.33	**38.63**	**16.89**	**2.40**
	Day	Clear, cold and not dry / ON	4332	51.98				
	Night	Clear, cold and dry / OFF	3234	56.14	4.63	**32.60**	**11.50**	-2.56
	Night	Clear, cold and not dry / ON	5449	51.51				

October 1, 2013 - April 15, 2014

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	5493	56.84	2.66	**31.69**	-4.09	-27.94
	Day	Clear, cold and not dry / ON	12084	54.18				
	Night	Clear, cold and dry / OFF	3633	56.65	3.79	**38.18**	**8.01**	-12.09
	Night	Clear, cold and not dry / ON	16533	52.86				
Sign 2	Day	Clear, cold and dry / OFF	7672	56.54	4.09	**39.13**	**10.48**	-8.61
	Day	Clear, cold and not dry / ON	21145	52.45				
	Night	Clear, cold and dry / OFF	2135	53.93	4.46	**22.08**	**7.24**	-2.63
	Night	Clear, cold and not dry / ON	12889	49.47				
Sign 3	Day	Clear, cold and dry / OFF	5359	50.08	5.24	**42.80**	**18.31**	**1.98**
	Day	Clear, cold and not dry / ON	7087	44.84				
	Night	Clear, cold and dry / OFF	13839	49.77	4.46	**56.41**	**18.45**	-6.84
	Night	Clear, cold and not dry / ON	15750	45.31				
Sign 4	Day	Clear, cold and dry / OFF	158407	57.26	1.53	**15.65**	-14.99	-35.42
	Day	Clear, cold and not dry / ON	16095	55.73				
	Night	Clear, cold and dry / OFF	3240	56.89	2.58	**26.67**	-4.24	-24.19
	Night	Clear, cold and not dry / ON	16819	54.31				

BOLD indicates significance

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

October 1, 2014 - April 15, 2015								
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	9897	56.64	2.10	**27.73**	-11.88	-38.29
	Day	Clear, cold and not dry / ON	9227	54.54				
	Night	Clear, cold and dry / OFF	1919	56.53	2.79	**19.52**	-1.47	-15.47
	Night	Clear, cold and not dry / ON	9860	53.74				
Sign 2	Day	Clear, cold and dry / OFF	411	50.61	2.48	**4.14**	-0.86	-4.20
	Day	Clear, cold and not dry / ON	3050	48.13				
	Night	Clear, cold and dry / OFF	286	54.24	8.94	**14.54**	**9.66**	**6.40**
	Night	Clear, cold and not dry / ON	3898	45.30				
Sign 3	Day	Clear, cold and dry / OFF	1026	53.91	3.36	**20.93**	0.70	**-12.78**
	Day	Clear, cold and not dry / ON	1475	50.55				
	Night	Clear, cold and dry / OFF	4355	53.13	3.10	**20.93**	0.70	-12.78
	Night	Clear, cold and not dry / ON	2739	50.03				
Sign 4	Day	Clear, cold and dry / OFF	2119	57.73	1.99	**13.04**	-6.63	-19.74
	Day	Clear, cold and not dry / ON	2971	55.74				
	Night	Clear, cold and dry / OFF	2400	56.29	2.02	**13.77**	-6.22	-20.22
	Night	Clear, cold and not dry / ON	6327	54.27				

BOLD indicates significance

A further illustration of the mean changes in speeds for day and night under clear, cold and dry versus not dry conditions are presented in Figure 3-1. The figure illustrates the fluctuations and extent of speed reductions for day and night over the study period. During the day, speed trends at each sign location behaved similarly during dry versus not dry conditions from year to year; for example, mean speed decreases occurred at all signs during the same year (except 2015). Speed reductions during daytime clear, cold and not dry conditions are within a range of 1 to 6 miles per hour, depending on the sign and year. Speed reductions at night were not as uniform from year to year at each sign. Instead, the reductions observed fluctuated by sign and by year. For example, in 2015, the average speed differences between dry and not dry conditions generally fell from the previous year, except at Sign 2, where the mean speed difference increased by approximately 4.5 miles per hour. Generally, mean speed reductions at night fell into a range between 1 and 7 miles per hour.

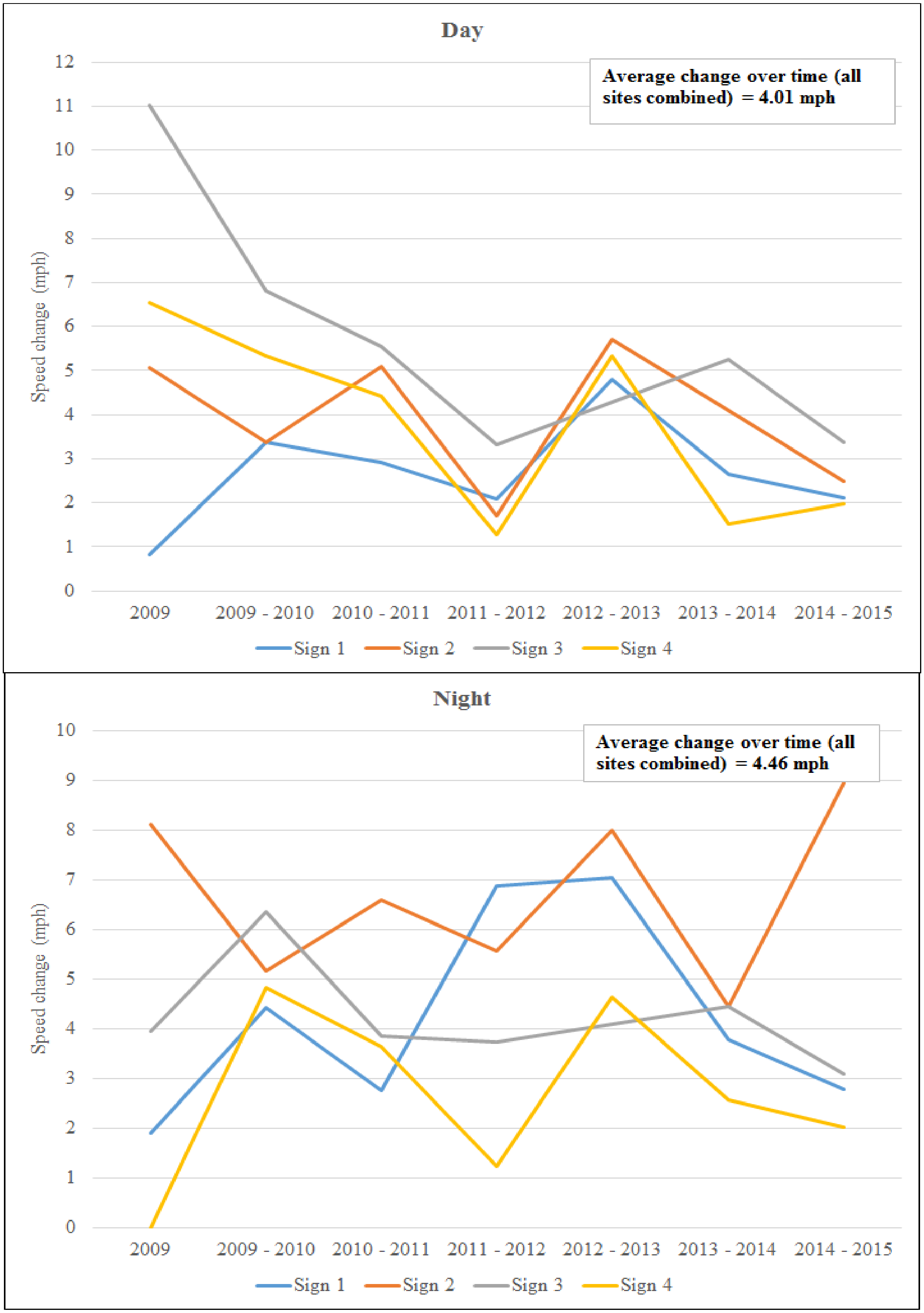

Figure 3-1 Mean speed differences for clear, cold and dry versus not dry conditions

3.3.4. Manned Chain Control

The final evaluation of mean speeds examined the impacts of manned chain control. The impacts of the ICWS on speeds when manned chain control is implemented, particularly higher levels, should 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 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 was 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 the entire study period (March 2008 – April 2015). The manned chain control levels observed for the period 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 totaling approximately 4,400 hours, this would equate to manned chain control being in effect for approximately 440 hours, keeping in mind it would not be continuously staffed. Meanwhile, the ICWS is continuously active throughout the entire winter season.

The following tables present the results of evaluations related to the status of each sign (on versus off), the time of day and the different chain control levels of interest.

Table 3-6 Watch signage speed differences

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)**
Sign 1	Off-Night	26	55.19	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	483	54.87	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 2	Off-Night	11	47.90	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	330	52.70	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 3	Off-Night	30	50.70	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	512	53.13	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 4	Off-Night	11	53.20	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	311	57.49	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
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)**
Sign 1	Off-Night	121	55.85	0.93	**2.06**	-4.58	-9.02
	On-Night	1031	54.92				
	Off-Day	550	56.61	2.57	**9.54**	-1.60	-9.02
	On-Day	1584	54.04				
Sign 2	Off-Night	153	54.79	-1.71	-2.66	-7.34	-10.47
	On-Night	412	56.50				
	Off-Day	718	51.36	-1.84	-3.30	-8.68	-12.27
	On-Day	814	53.20				
Sign 3	Off-Night	816	54.00	3.09	**7.57**	0.22	-4.66
	On-Night	347	50.91				
	Off-Day	1591	54.72	5.39	**18.83**	**8.35**	1.37
	On-Day	627	49.33				
Sign 4	Off-Night	1033	57.48	3.00	**8.62**	0.07	-5.36
	On-Night	372	54.48				
	Off-Day	1529	58.59	2.60	**8.13**	-1.22	-7.46
	On-Day	512	55.99				

BOLD indicates significance

Table 3-6 cont'd 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)
October 1, 2010 - April 15, 2011							
No Watch restrictions occurred in this year							
October 1, 2011 - April 15, 2012							
No Watch restrictions occurred in this year							
October 1, 2012 - April 15, 2013							
No Watch restrictions occurred in this year							
October 1, 2013 - April 15, 2014							
Sign 1	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	9	50.55	-0.02	0.00	-1.49	-2.48
	On-Day	66	50.57				
October 1, 2014 - April 15, 2015							
No Watch restrictions occurred in this year							

Table 3-7 R-1 Modified signage speed differences

March 12, 2009 - April 15, 2009							
No R-1 Modified restrictions occurred in this year							
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)**
Sign 1	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	1304	41.89				
	Off-Day	198	50.69	7.38	**13.55**	**8.03**	**4.36**
	On-Day	1874	43.31				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	799	38.00				
	Off-Day	59	50.32	10.91	**8.98**	**6.50**	**4.86**
	On-Day	962	39.41				
Sign 3	Off-Night	25	48.24	10.22	**6.68**	**4.72**	**3.41**
	On-Night	1031	38.02				
	Off-Day	363	47.09	9.07	**21.08**	**14.10**	**9.45**
	On-Day	1607	38.02				
Sign 4	Off-Night	45	58.28	13.43	**16.83**	**13.07**	**10.54**
	On-Night	1607	44.85				
	Off-Day	323	52.25	8.49	**18.86**	**12.19**	**7.75**
	On-Day	1278	43.76				
October 1, 2010 - April 15, 2011							
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	0	0.00				
	Off-Day	121	49.38	6.14	**10.68**	**5.46**	**1.98**
	On-Day	1286	43.24				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	412	38.92				
	Off-Day	160	45.60	5.35	**8.82**	**3.87**	0.57
	On-Day	732	40.25				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	593	37.08				
	Off-Day	260	46.45	7.58	**18.83**	**11.37**	**6.40**
	On-Day	1324	38.87				
Sign 4	Off-Night	11	52.81	9.34	**6.31 (1)**	**4.28 (1)**	**2.93 (1)**
	On-Night	626	43.47				
	Off-Day	235	52.79	7.94	**16.85**	**10.49**	**6.24**
	On-Day	1201	44.85				

BOLD indicates significance

(1) Critical value = 2.20

Table 3-7 R-1 cont'd Modified signage speed differences

October 1, 2011 - April 15, 2012							
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	373	44.46	8.05	**14.64**	**9.18**	**5.55**
	On-Night	1100	36.41				
	Off-Day	856	55.12	12.68	**42.80**	**32.68**	**25.92**
	On-Day	873	42.44				
Sign 2	Off-Night	148	40.30	4.65	**10.36**	**3.67**	**-0.78**
	On-Night	900	35.65				
	Off-Day	271	48.77	10.41	**16.06**	**11.43**	**8.34**
	On-Day	924	38.36				
Sign 3	Off-Night	951	52.46	14.78	**50.68**	**40.39**	**33.54**
	On-Night	763	37.68				
	Off-Day	2326	54.36	14.00	**47.88**	**37.62**	**30.78**
	On-Day	555	40.36				
Sign 4	Off-Night	131	50.48	6.41	**10.37**	**5.51**	**2.27**
	On-Night	621	44.07				
	Off-Day	506	54.24	6.60	**18.12**	**9.88**	**4.38**
	On-Day	878	47.64				
October 1, 2012 - April 15, 2013							
Site	**Condition**	**Sample Size**	**Mean**	**Δ mph**	**t stat Δ of 0 mph @ 0.05 (1.64)**	**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	208	41.85				
	Off-Day	77	43.87	2.74	**2.79**	-0.27	-2.31
	On-Day	96	41.13				
Sign 2	Off-Night	4	35.75	-3.78	-1.54	-2.76	-3.58
	On-Night	118	39.53				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	409	39.40				
Sign 3	Off-Night	Data unavailable for this site					
	On-Night						
	Off-Day						
	On-Day						
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	197	41.89				
	Off-Day	33	50.45	5.14	**5.57 (1)**	**2.31 (1)**	0.14 (1)
	On-Day	430	45.31				

BOLD indicates significance

(1) Critical value = 2.01

Table 3-7 R-1 cont'd Modified signage speed differences

October 1, 2013 - April 15, 2014

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	791	38.76	-3.08	-10.48	-20.71	-27.53
	On-Night	457	41.84				
	Off-Day	311	44.42	1.81	**3.58**	-2.35	-6.30
	On-Day	340	42.61				
Sign 2	Off-Night	119	35.91	-7.51	-8.97	-12.55	-14.94
	On-Night	143	43.42				
	Off-Day	148	37.90	-2.54	-4.20	-9.16	-12.47
	On-Day	311	40.44				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	120	35.95				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	349	35.90				
Sign 4	Off-Night	72	49.05	5.09	**6.47 (1)**	**2.77 (1)**	0.12 (1)
	On-Night	440	43.96				
	Off-Day	42	54.38	8.37	**10.15 (2)**	**6.51 (2)**	**4.08 (2)**
	On-Day	878	46.01				

October 1, 2014 - April 15, 2015

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	4	43.75	1.21	0.2 (3)	-0.30	-0.63
	On-Night	271	42.54				
	Off-Day	48	53.43	11.24	**11.49**	**8.42**	**6.38**
	On-Day	136	42.19				
Sign 2	Off-Night	17	36.82	-0.69	-0.72	-3.86	-5.95
	On-Night	423	37.51				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	256	38.77				
Sign 3	Off-Night	12	43.33	3.71	1.30 (4)	0.25 (4)	-0.45
	On-Night	8	39.62				
	Off-Day	49	47.95	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 4	Off-Night	61	43.18	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	107	49.08				

BOLD indicates significance

(1) Critical value = 2.01

(2) Critical value = 2.00

(3) Critical value = 2.16

(4) Critical value = 2.35

Table 3-8 R-1 signage speed differences

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)**
Sign 1	Off-Night	55	35.54	N/A	N/A	N/A	N/A
	On-Night	0	0				
	Off-Day	45	41.77	N/A	N/A	N/A	N/A
	On-Day	0	0				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	87	37.49	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 3	Off-Night	30	34.50	-4.75	-2.69	-4.39	-5.53
	On-Night	16	39.25				
	Off-Day	16	40.19	1.81	**17.31 (1)**	-11.29	-30.37
	On-Day	22	38.38				
Sign 4	Off-Night	37	38.29	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	25	52.00	10.04	**5.85 (2)**	**4.10 (2)**	**2.93 (2)**
	On-Day	23	41.96				
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)**
Sign 1	Off-Night	53	41.07	0.88	0.92	-2.23	-4.33
	On-Night	1354	40.19				
	Off-Day	148	49.12	8.46	**13.28**	**8.57**	**5.43**
	On-Day	2439	40.66				
Sign 2	Off-Night	16	34.00	-2.69	-2.10	-4.44	-6.00
	On-Night	909	36.69				
	Off-Day	80	38.63	1.12	1.29	-2.15	-4.44
	On-Day	1270	37.51				
Sign 3	Off-Night	46	40.23	4.04	**3.70**	0.95	-0.87
	On-Night	889	36.19				
	Off-Day	279	48.61	12.16	**32.74**	**24.66**	**19.27**
	On-Day	1664	36.45				
Sign 4	Off-Night	119	51.34	9.90	**19.29**	**13.44**	**9.54**
	On-Night	1499	41.44				
	Off-Day	235	54.92	12.52	**33.31**	**25.33**	**20.01**
	On-Day	1721	42.40				

BOLD indicates significance

(1) Critical value = 2.13

(2) Critical value = 2.01

Table 3-8 cont'd R-1 signage speed differences

October 1, 2010 - April 15, 2011							
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				
	On-Night	0	0	N/A	N/A	N/A	N/A
	Off-Day	103	47.38				
	On-Day	1321	40.56	6.82	**9.49**	**5.31**	**2.53**
Sign 2	Off-Night	3	37.66				
	On-Night	835	36.84	0.82	0.35	-0.93	-1.78
	Off-Day	91	40.19				
	On-Day	717	38.38	1.81	**2.76**	-1.80	-4.48
Sign 3	Off-Night	7	43.85				
	On-Night	1015	35.78	8.07	**4.45 (1)**	**2.80 (1)**	1.69 (1)
	Off-Day	106	45.60				
	On-Day	1151	37.54	8.06	**12.23**	**7.67**	**4.63**
Sign 4	Off-Night	17	54.00				
	On-Night	1413	41.28	12.72	**14.76 (2)**	**11.28 (2)**	**8.95 (2)**
	Off-Day	141	53.61				
	On-Day	1158	42.86	10.75	**19.09**	**13.76**	**10.21**
October 1, 2011 - April 15, 2012							
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	164	40.53				
	On-Night	1668	36.89	3.64	**4.18**	0.73	-1.55
	Off-Day	65	44.70				
	On-Day	1299	39.56	5.14	**4.88**	**2.03**	0.13
Sign 2	Off-Night	66	40.59				
	On-Night	1067	38.37	2.22	**4.18**	-1.47	-5.24
	Off-Day	75	41.50				
	On-Day	1001	36.87	4.63	**4.18**	1.47	-0.32
Sign 3	Off-Night	1278	53.80				
	On-Night	1471	45.79	8.01	**27.73**	**17.34**	**10.42**
	Off-Day	1748	54.27				
	On-Day	436	37.13	17.14	**62.67**	**51.70**	**44.39**
Sign 4	Off-Night	27	47.03				
	On-Night	1091	40.73	6.30	6.13 (3)	3.21 (3)	1.28 (3)
	Off-Day	26	52.30				
	On-Day	1154	42.42	9.88	9.64 (3)	6.71 (4)	4.76 (4)

BOLD indicates significance
(1) Critical value = 2.36
(2) Critical value = 2.10
(3) Critical value = 2.04
(4) Critical value = 2.05

Table 3-8 cont'd R-1 signage speed differences

October 1, 2012 - April 15, 2013							
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	53	38.24	0.01	0.02	-4.42	-7.38
	On-Night	1394	38.23				
	Off-Day	79	39.75	-1.44	-2.14	-6.64	-9.63
	On-Day	427	41.19				
Sign 2	Off-Night	80	33.22	-3.75	-8.63	-15.54	-20.14
	On-Night	980	36.97				
	Off-Day	123	34.89	-3.15	-9.01	-17.60	-23.32
	On-Day	1397	38.04				
Sign 3	Off-Night	Data unavailable for this site					
	On-Night						
	Off-Day						
	On-Day						
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	1015	40.91				
	Off-Day	16	55.00	12.15	**9.72 (1)**	**7.32 (1)**	**5.72 (1)**
	On-Day	975	42.85				
October 1, 2013 - April 15, 2014							
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	169	38.37	-2.24	-4.09	-9.59	-13.25
	On-Night	186	40.61				
	Off-Day	471	42.09	0.53	0.78	-3.73	-6.75
	On-Day	95	41.56				
Sign 2	Off-Night	67	36.13	-3.44	-4.29	-8.04	-10.54
	On-Night	121	39.57				
	Off-Day	110	38.88	-0.08	-0.10	-3.79	-6.25
	On-Day	229	38.96				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	126	35.41				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	224	36.34				
Sign 4	Off-Night	3	50.00	7.28	**6.74 (2)**	**3.96 (2)**	2.10 (2)
	On-Night	405	42.72				
	Off-Day	28	54.75	9.42	**10.25 (3)**	**6.98 (3)**	**4.80 (3)**
	On-Day	627	45.33				
BOLD indicates significance							
(1) Critical value = 2.11							
(2) Critical value = 3.18							
(3) Critical value = 2.03							

Table 3-8 cont'd R-1 signage speed differences

October 1, 2014 - April 15, 2015							
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	428	39.77				
	Off-Day	69	47.21	8.36	**8.09**	**5.19**	**3.25**
	On-Day	408	38.85				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	595	34.40				
	Off-Day	4	36.50	2.00	1.37 (1)	-0.69	-2.06
	On-Day	776	34.50				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	38	40.84	5.67	**4.09 (2)**	1.92 (2)	0.48 (2)
	On-Day	34	35.17				
Sign 4	Off-Night	19	41.89	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	721	44.20				

BOLD indicates significance

(1) Critical value = 2.35

(2) Critical value = 2.00

Table 3-9 R-2 signage speed differences

March 12, 2009 - April 15, 2009							
No R-2 restrictions occurred in this year							
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)**
Sign 1	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	363	39.27				
	Off-Day	49	48.04	8.07	**6.46**	**4.06**	**2.45**
	On-Day	89	39.97				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	346	36.36				
	Off-Day	4	46.25	9.65	2.22 (1)	1.53 (1)	1.06 (1)
	On-Day	73	36.60				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	267	35.29				
	Off-Day	40	44.30	8.14	**6.03 (2)**	**3.81 (2)**	**2.32 (2)**
	On-Day	78	36.16				
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	566	41.31				
	Off-Day	61	54.77	9.84	**9.53**	**6.62**	**4.68**
	On-Day	272	44.93				
October 1, 2010 - April 15, 2011							
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	6	38.66	0.77	0.30 (3)	-0.87	-1.65
	On-Night	278	37.89				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	168	39.50				
Sign 2	Off-Night	3	36.66	-0.09	-0.03	-1.15	-1.89
	On-Night	261	36.75				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	780	37.32				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	219	35.72				
	Off-Day	13	41.61	3.92	**2.38 (4)**	0.56 (4)	-0.65
	On-Day	189	37.69				
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	0	0.00				

BOLD indicates significance

(1) Critical value = 3.18

(2) Critical value = 2.00

(3) Critical value = 2.57

(4) Critical value = 2.16

Table 3-9 cont'd R-2 signage speed differences

October 1, 2011 - April 15, 2012							
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	29	52.31	10.80	**5.03 (1)**	**3.63 (1)**	**2.70 (1)**
	On-Night	27	41.51				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	233	40.61				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	53	34.30				
	Off-Day	27	53.44	17.00	**8.64 (2)**	**7.11 (2)**	**6.09 (2)**
	On-Day	186	36.44				
Sign 3	Off-Night	158	53.12	16.12	5.32 (3)	4.33 (3)	3.67 (3)
	On-Night	2	37.00				
	Off-Day	278	54.08	12.92	18.04	13.85	11.06
	On-Day	125	41.16				
Sign 4	Off-Night	100	45.35	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	298	40.94				
October 1, 2012 - April 15, 2013							
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	0.00	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	0.00	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	87	37.24				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	161	36.10				
Sign 3	Off-Night	Data unavailable for this site					
	On-Night						
	Off-Day						
	On-Day						
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	57	38.87				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	100	37.99				
BOLD indicates significance							
(1) Critical value = 2.01							
(2) Critical value = 2.05							
(3) Critical value = 12.70							

Table 3-9 R-2 cont'd signage speed differences

October 1, 2013 - April 15, 2014

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	0.00	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	0.00	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 2	Off-Night	0	0.00	0.00	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	0.00	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 3	Off-Night	0	0.00	0.00	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	0.00	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	0	0.00				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	59	49.96				

October 1, 2014 - April 15, 2015

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	230	33.80				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	53	37.62				
Sign 2	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	63	34.57				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	0	0.00				
Sign 3	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	3	31.33				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	31	34.88				
Sign 4	Off-Night	0	0.00	N/A	N/A	N/A	N/A
	On-Night	130	39.90				
	Off-Day	0	0.00	N/A	N/A	N/A	N/A
	On-Day	44	42.11				

As the results presented in the previous tables indicate, it appears that the greatest impact of the ICWS is when R-1 control is in effect. However, that impact has tapered off in more recent years. Still, this general observation 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. Finally, the differences between speeds when the ICWS was on and off for the R-2 chain condition (the ICWS was always on) could only be completed for the initial years following deployment, as this level of control was not observed in conjunction with available speed data measurements in later years. When such analysis could be completed, statistically significant speed differences generally were observed during the day.

3.4. 85th Percentile Speed Comparisons

In addition to examining the statistical significance of mean speed changes, 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 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. As the results indicate, 85th percentile speed differences initially increased in the seasons following system deployment. In more recent seasons, these differences have fallen somewhat, although in most cases they remain above 2 miles per hour. Given that the status of the system being on versus off is fairly aggregate, more detailed breakdowns of time of day and weather conditions may yield more notable differences.

Table 3-10 85th percentile speed evaluation results: 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
	October 2011 - April 2012	61	59	2
	October 2012 - April 2013	61	58	3
	October 2013 - April 2014	61	59	2
	October 2014 - April 2015	61	59	2
Sign 2	March 2009 - April 2009	62	60	2
	October 2009 - March 2010	63	59	4
	October 2010 - April 2011	63	57	6
	October 2011 - April 2012	62	61	1
	October 2012 - March 2013	63	58	5
	October 2013 - March 2014	63	60	3
	October 2014 - April 2015	64	59	5
Sign 3	March 2009 - April 2009	61	56	5
	October 2009 - March 2010	60	54	6
	October 2010 - April 2011	59	54	5
	October 2011 - April 2012	60	57	3
	October 2012 - March 2013	Data not available		
	October 2013 - March 2014	58	53	5
	October 2014 - April 2015	60	56	4
Sign 4	March 2009 - April 2009	63	60	3
	October 2009 - March 2010	62	59	3
	October 2010 - April 2011	62	59	3
	October 2011 - April 2012	62	61	1
	October 2012 - March 2013	62	59	3
	October 2013 - March 2014	62	60	2
	October 2014 - April 2015	62	60	2

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 results indicate, the 85th percentile speed differences between day and night and system status were similar to those observed between the on versus off condition. The one item to note is that speed differences at night were typically greater than those observed during the day, which was expected. Drivers encountering a warning at night could be expected to reduce their speed to a greater extent due to a reduced ability to judge surface conditions, and the data bore this out.

Table 3-11 85th percentile speed evaluation results: 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
	October 2011 - April 2012	61	59	2	61	59	2
	October 2012 - April 2013	61	59	2	61	57	4
	October 2013 - April 2014	61	60	1	61	59	2
	October 2014 - April 2015	61	60	1	61	59	2
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
	October 2011 - April 2012	63	61	2	62	59	3
	October 2012 - April 2013	63	58	5	62	56	6
	October 2013 - April 2014	63	60	3	62	59	3
	October 2014 - April 2015	64	60	4	63	58	5
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
	October 2011 - April 2012	60	57	3	59	57	2
	October 2012 - April 2013	Data not available					
	October 2013 - April 2014	58	53	5	57	53	4
	October 2014 - April 2015	60	56	4	59	56	3
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
	October 2011 - April 2012	62	61	1	61	60	1
	October 2012 - April 2013	62	59	3	61	59	2
	October 2013 - April 2014	62	60	2	61	60	1
	October 2014 - April 2015	62	61	1	61	60	1

3.4.3. Weather Conditions

Table 3-12 presents the results of 85th percentile speed differences during wet weather. 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 mean speed conditions. During the day, mean speed differences generally fell within the 2 to 5 mile per hour range. The sign locations within the corridor (Sign 2 and Sign 3) displayed slightly higher speed differences than the outer signs, which could be indicative of drivers in the corridor being more cautious after receiving an initial warning for the prior set of curves. Speed differences during night hours were more pronounced during the initial years following system deployment, but have tended to fluctuate lower in more recent years. During most seasons, speed differences were 3 miles per hour or greater. Interestingly, speed differences at night were not always greater than those observed during the day. One would have expected a majority of drivers to travel at lower speeds during wet conditions at night, but this not always the case. There is not a clear indication as to why this was the case.

Table 3-12 85th percentile speed evaluation results: precipitation

		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
	October 2011 - April 2012	61	58	3	61	52	9
	October 2012 - April 2013	61	59	2	61	52	9
	October 2013 - April 2014	61	59	2	60	57	3
	October 2014 - April 2015	61	59	2	61	59	2
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	5	63	48	15
	October 2011 - April 2012	63	58	5	52	50	2
	October 2012 - April 2013	63	58	5	62	49	13
	October 2013 - April 2014	63	59	4	62	59	3
	October 2014 - April 2015	64	60	4	63	60	3
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
	October 2011 - April 2012	60	56	4	59	55	4
	October 2012 - April 2013	Data not available					
	October 2013 - April 2014	58	53	5	57	53	4
	October 2014 - April 2015	60	56	4	60	55	5
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
	October 2011 - April 2012	62	60	2	61	57	4
	October 2012 - April 2013	62	59	3	61	56	5
	October 2013 - April 2014	62	60	2	61	58	3
	October 2014 - April 2015	62	61	1	61	58	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 (e.g., 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, speed reductions during the day were variable when clear, cold and icy conditions were present. In general, speed decreases of 1 to 5 miles per hour were observed. Higher reductions were observed at the inner sign locations (Signs 2 and 3) compared to the signs located at either end of the corridor. The results indicate that the warning message has produced a change in speed behaviors during the day for the targeted condition, that is, clear, cold and not dry conditions. At night, similar results were observed, with inner sign locations producing slightly higher speed differences than the outer signs. Speed differences tended to fluctuate between seasons, so no discernable increasing or decreasing pattern was noted. One notable result was the 9 mile per hour difference when a warning was presented during the 2014-2015 season at Sign 2. The cause for this change is not clear, but the location had previously experienced higher speed reductions compared to other signs as well.

Table 3-13 85th percentile speed evaluation results: clear, cold and dry versus not dry

		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
	October 2011 - April 2012	61	60	1	61	60	1
	October 2012 - April 2013	61	58	3	61	58	3
	October 2013 - April 2014	61	60	1	61	59	2
	October 2014 - April 2015	61	60	1	61	60	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
	October 2011 - April 2012	62	61	1	62	60	2
	October 2012 - April 2013	63	59	4	62	56	6
	October 2013 - April 2014	63	61	2	62	59	3
	October 2014 - April 2015	62	59	3	65	56	9
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
	October 2011 - April 2012	60	57	3	59	57	2
	October 2012 - April 2013	Data not available					
	October 2013 - April 2014	57	52	5	57	53	4
	October 2014 - April 2015	59	57	2	59	57	2
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
	October 2011 - April 2012	62	61	1	61	60	1
	October 2012 - April 2013	62	59	3	61	59	2
	October 2013 - April 2014	61	61	0	61	60	1
	October 2014 - April 2015	62	61	1	61	60	1

* Limited sample size

3.5. Chapter Conclusion

The results of the statistical analysis of speed data, specifically the analyses performed for clear, cold and dry/not dry conditions, suggest that the system is working as intended and that vehicle speeds are significantly lower. As one would expect, mean speeds were significantly different from each other (off versus on) overall 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 were examined, it was once again found that mean speeds were significantly different from each other overall and differed by greater than 5 mph. When general wet weather (snow, rain, etc.) conditions were evaluated, it was found that mean speeds were significantly different from one another (wet versus dry) overall and differed by greater than 5 mph. Of course, such 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 during most seasons. However, statistically significant mean speed differences greater than 5 mph were observed less frequently overall. 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. This reduction appears to be translating into a long-term safety benefit (i.e., reduced crashes in the curves of interest), as the results of the next chapter will illustrate. Bear in mind that the speed readings employed in this evaluation were collected at sign locations in advance of the signs themselves, and 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, statistically significant mean speeds differences of greater than 5 mph were most frequently observed among all chain control categories. 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.

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. 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.

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, dynamic 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 critical component of this work was the analysis of crash data and longer term 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 of 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. 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 (15). Carson and Mannering (7) 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 (7). 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 (7).

Limited studies were identified on the safety effects of more active 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) (4). 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) (4). 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 6.75 years of the after period data (July 1, 2008 – April 15, 2015) were chosen for this safety evaluation.

Crash data were obtained from Caltrans' Traffic Accident Surveillance and Analysis System (TASAS) database and California Highway Patrol crash records 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 48 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 104 crashes, 57 (55%) 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 10+ 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 23 of the 48 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 10 of the 23 crashes during which the system was turned on was reported as being cloudy or snowing. It is interesting that 13 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
	2010	12	15 (10)	4 (3)	9 (6)	1 (1)	2400
	2011	12	3 (3)	2 (2)	1 (1)	0	2400
	2012	12	6 (2)	4 (1)	1 (1)	0	2400
	2013	12	7 (3)	7 (2)	1 (1)	0	2200
	2014	12	3 (2)	2 (1)	1 (1)	0	N/A
	2015	3.5	1 (0)	0	0	0	N/A

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 icy curve warning systems 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 into 2010. 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 2015.

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 Caltrans study (16), 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 (17,18), which is used to determine the change in safety in terms of crash counts:

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

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 (17) 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 (19, 20, 21, 22, 23, 24, 25, 26, 27, 28).

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) (18) 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):

$$N_{spf} = AADT * 365 * L * 10^{-6} * e^{(-0.312)} \tag{3}$$

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 over-dispersion parameter associated with Equation 2 determined by $k = 0.236/L$. As indicated in the HSM (18), the closer the value k is to zero, the more statistically reliable the SPF. Combining those tangent segments with the 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 55.04, with a standard deviation of 5.55 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 2,500 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	3.1	0	4.02	1.89
2	Horizontal Curve Set	1.05	6	5.07	4	6.58	3.21
3	Horizontal Curve	0.27	5	3.39	8	4.4	2.43
4	Horizontal Curve	0.21	2	1.46	2	1.89	0.96
5	Horizontal Curve	0.11	1	0.78	4	1.01	0.53
6	Tangent	0.35	0	0.64	0	0.83	0.36
7	Horizontal Curve	0.16	2	1.45	0	1.87	1.02
8	Tangent	0.55	5	3.44	2	5.08	2.39
9	Horizontal Curve	0.12	3	1.99	3	2.58	1.46
10	Horizontal Curve	0.11	6	4.33	5	4.74	3.18
11	Horizontal Curve Set	0.46	1	1.53	7	1.99	1.03
12	Horizontal Curve	0.14	8	5.54	3	7.18	4.64
13	Horizontal Curve Set	0.44	9	6.74	3	8.74	5.44
14	Tangent	0.24	3	2.18	4	2.82	1.53
15	Horizontal Curve	0.16	1	0.96	2	1.25	0.72
	Total	**5**	**56**	**42.59**	**47**	**55.04**	**30.83**

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 30 in the after period. Most of the crashes which occurred between April and September were under dry pavement conditions.

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 (17):

$$\boldsymbol{\theta} = \frac{\boldsymbol{\lambda/\pi}}{\mathbf{1}+\boldsymbol{Var(\pi)/\pi^2}} = \frac{\mathbf{47\ /\ 55.04}}{\mathbf{1+30.83/55.04^2}} = \mathbf{0.85}$$

The variance of θ was calculated by:

$$Var(\theta) = \frac{\theta^2 * (\frac{Var(\lambda)}{\lambda^2} + \frac{Var(\pi)}{\pi^2})}{(1+\frac{Var(\pi)}{\pi^2})} = 0.02$$

The value of θ indicates that the deployment of the Fredonyer Pass ICWS reduced the number of crashes by 15 percent during the after period for the study section. It is noted that the crash reduction factor (θ =0.85) 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 15 percent 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 4 crashes were observed to occur along this curve after deployment. The Empirical Bayes estimate of expected crashes for this curve during the after period (i.e., estimating expected crashes without the ICWS present) was 6.58 crashes. Consequently, when comparing the expected number of crashes (6.58) to the number that occurred (4), it appears that the ICWS may have contributed to a reduction in crashes at this location. Note 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 6 crashes were observed. The Empirical Bayes estimate for crashes for the after period was 15.92 crashes, compared to the 6 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 10 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 24.5 crashes were estimated for the after period by the Empirical Bayes approach, which is higher than the 10 crashes that actually occurred during the period. Although some 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 (18) 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 per 100,000 vehicles passing through the site) for different severity levels were calculated (Table 4-4). The crash rates in the before period were adjusted by $\frac{AADT_{after}}{AADT_{before}} = 0.86$ to compare with those in the after period. The results show that the crash rate for PDO crashes was reduced from 5.51 to 2.14 crashes per winter season. The crash rate for Injury crashes decreased from 2.42 to 2.00 crashes per season. Finally, the Fatal crash rate fell from 0.44 during the before period to 0.14 during the after period. Based on these observations, it appears that the ICWS has reduced crash severities over time. This analysis, however, is similar to the naïve before-after study as it does not take RTM into account. When viewed collectively though, the 4.5-year before period and 6.75 year after period (7 full winter seasons) provides a reasonable duration for evaluation.

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	4.29	2.14	2.00	0.14	2.14

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 (29). 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 2015 was 1.60, according to the Bureau of Labor Statistics (30). 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:

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

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 $1.03 million per winter season (present value). This represents an estimation of the financial savings accrued by the ICWS through improved safety following deployment.

There is also utility in comparing this approximate seasonal benefit value to the collective costs associated with maintaining and operating the system on a seasonal basis. Information provided by District 2 ITS Engineering on the electrical maintenance staff cost, ITS engineering and support staff cost, power and communications costs from 2012 through 2014 provide a perspective on what is required financially to keep the ICWS functioning. In 2012, the total cost to maintain the ICWS was $15,355, while it was $37,377 and $33,959 in 2013 and 2014, respectively. The average of these values over the three year reporting period was $28,897. Regardless of whether the actual value for each year or the average is compared to the $1.03 million benefit produced by the system, it is clear that the ICWS shows a significant benefit when compared to a year of maintenance costs. If a rough benefit-cost ratio calculation is made for each year (2012-2014), the resulting values are

67.07, 27.55 and 30.33, respectively. If considering the lowest of these benefit-cost ratios, the ICWS still produces a significant benefit in crash cost savings versus annual maintenance costs.

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 April 15, 2015. 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.

As the data in the Table 4-5 indicates, 42 of the 48 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 23 of the 48 crashes, the ICWS was also activated, indicating that the recorded road surface condition was accurate. Interestingly, of the 48 crashes, 40 occurred during daylight hours.

Only six crashes occurred during a time when manned chain control was active (all of these during R-1[4] control). The contributing cause of these crashes was speeding in four cases, "other than driver" in one case and alcohol in one case. The ICWS was on at the time of two of these crashes, off at the time of two crashes, and its state unknown (data recording error at the site) during the fifth crash. For crashes where the system was turned on, speeding was listed as the contributing factor, which indicates that drivers may not have heeded the warning presented by the system. An additional two crashes occurred while the system was on and R1-M chain control was in effect. Speeding and other factors aside from the driver were listed for these crashes. In the case of other contributing factors, it is unclear to what extent the ICWS warning may have been heeded.

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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.

In summary, the number of crashes which occurred under (or shortly before) manned chain control during the after period was relatively low. 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 while chain controls are in place. Second, although “before” period manned chain control data was not 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 to be 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.

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
13	1/11/2010	7:35	12.33	WB	Influence of Alcohol	Injury	0	2	Cloudy	Snowy, Icy	Daylight	None	On
14	1/14/2010	8:53	14.20	WB	Speeding	PDO	0	0	Clear	Snowy, Icy	Daylight	None	On
15	1/14/2010	9:03	14.22	WB	Speeding	Injury	0	1	Clear	Snowy, Icy	Daylight	None	On
16	1/14/2010	9:36	14.24	WB	Speeding	Injury	0	1	Clear	Dry	Daylight	None	On
17	01/17/10	21:15	10.95	EB	Speeding	Injury	0	1	Cloudy	Snowy, Icy	Dark	**R-1M**	On
18	03/30/10	4:15	13.29	WB	Speeding	PDO	0	0	Snowing	Snowy, Icy	Dark	None	N/A
19	4/27/2010	8:38	11.75	WB	Speeding	Injury	0	2	Snowing	Snowy, Icy	Daylight	None	N/A
20	04/28/10	7:40	10.15	EB	Speeding	PDO	0	0	Cloudy	Wet	Daylight	**R-1M**	N/A
21	09/08/10	10:30	10.46	WB	Speeding	Injury	0	2	Cloudy	Dry	Daylight	None	N/A
22	10/23/2010	11:30	12.62	EB	Speeding	Injury	0	2	Cloudy	Wet	Daylight	None	Off
23	11/19/2010	15:36	11.89	WB	Influence of Alcohol	Injury	0	2	Cloudy	Snowy, Icy	Daylight	**R-1**	Off
24	11/19/2010	14:04	12.50	EB	Speeding	PDO	0	0	Snowing	Wet	Daylight	**R-1**	Off
25	11/23/2010	11:05	13.50	WB	Speeding	Injury	0	1	Cloudy	Snowy, Icy	Daylight	**R-1**	On
26	12/23/2010	10:15	12.90	EB	Speeding	PDO	0	0	Cloudy	Snowy, Icy	Daylight	None	On
27	12/24/10	15:10	10.92	EB	Speeding	Fatal	1	4	Clear	Snowy, Icy	Daylight	None	On
28	2/14/2011	7:20	14.14	WB	Speeding	Injury	0	1	Snowing	Snowy, Icy	Daylight	None	N/A
29	02/15/11	18:30	13.20	EB	Speeding	PDO	0	0	Snowing	Snowy, Icy	Dark	**R-1**	N/A
30	11/27/2011	9:00	11.10	EB	Speeding	PDO	0	0	Clear	Snowy, Icy	Daylight	None	On
31	2/2/2012	13:30	12.62	EB	Speeding	PDO	0	0	Clear	Dry	Daylight	None	On
32	07/25/12	N/A	13.60	N/A	N/A	PDO	N/A	N/A	Clear	Dry	Daylight	None	N/A
33	10/03/12	N/A	10.60	N/A	N/A	PDO	N/A	N/A	Clear	Dry	Dark	None	Off
34	10/27/12	N/A	11.48	N/A	N/A	PDO	N/A	N/A	Clear	Snowy, Icy	Daylight	None	On
35	11/24/12	N/A	11.10	N/A	N/A	Injury	N/A	N/A	Clear	Snowy, Icy	Daylight	None	On
36	12/07/12	N/A	13.10	N/A	N/A	PDO	N/A	N/A	Clear	Dry	Daylight	None	Off
37	02/07/13	N/A	13.50	N/A	N/A		N/A	N/A	Cloudy	Snowy, Icy	Daylight	Unknown	N/A
38	03/25/13	N/A	10.69	N/A	N/A	PDO	N/A	N/A	Cloudy	Dry	Daylight	None	Off
39	03/27/13	N/A	11.75	N/A	N/A	PDO	N/A	N/A	Cloudy	Dry	Dark	None	Off
40	06/18/13	N/A	14.48	N/A	N/A	PDO	N/A	N/A	Clear	Dry	Daylight	None	N/A
41	07/01/13	N/A	12.95	N/A	N/A	PDO	N/A	N/A	Clear	Dry	Dark	None	N/A
42	11/17/13	N/A	11.07	N/A	N/A	PDO	N/A	N/A	Clear	Snowy, Icy	Daylight	None	On
43	11/21/13	N/A	10.97	N/A	N/A	PDO	N/A	N/A	Clear	Snowy, Icy	Daylight	None	On
44	12/29/13	N/A	12.64	N/A	N/A	PDO	N/A	N/A	Cloudy	Dry	Daylight	None	On
45	02/17/14	N/A	10.95	N/A	N/A	PDO	N/A	N/A	Clear	Snowy, Icy	Daylight	None	Off
46	02/27/14	N/A	12.65	N/A	N/A	PDO	N/A	N/A	Cloudy	Dry	Dark	Unknown	Off
47	11/11/14	N/A	11.51	N/A	N/A	Injury	N/A	N/A	Clear	Snowy, Icy	Daylight	None	Off
48	03/27/15	N/A	13.88	N/A	N/A	Injury	N/A	N/A	Clear	Dry	Daylight	None	Off

Notes: ICWS state corresponds to the signage/system the driver would have most recently encountered; N/A indicates only partial crash data was available from record.

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 into 2010. 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.

Compared with ice warning signs and the Butte Creek ice warning system (4, 7), 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. 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. 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 (18), 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 longer term safety effects of ice or icy curve warning systems. 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 15%, which corresponds to an AMF of 0.85. 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 $1.03 million dollars per winter season during the "after deployment" study period. When compared to annual maintenance-related costs, this resulted in benefit-cost ratios ranging from 27.55 to 67.07, depending on the year of data being considered.

The results presented in this chapter are encouraging, as they represent the longer-term effectiveness of the ICWS. The analysis employed 6.75 years of after period data, which provides a good baseline for understanding whether the system is providing meaningful benefits. One point to note however, is that 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 eight of 48 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 to be 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 impact on 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

Since maintenance operations for State Route 36 at Fredonyer Pass are handled by Caltrans maintenance staff out of the Susanville maintenance yard, it was logical to obtain feedback related to the ICWS from personnel at this site. To obtain this feedback, a telephone interview was conducted with Ben McDaniel, Susanville Maintenance Supervisor. He has been in his current position for one month, serving as acting Maintenance Supervisor during the winter of 2014-2015. Overall, he has approximately 15 years of experience working out of the Susanville maintenance yard.

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 such as a snow plow dedicated to Lassen Rt. 36 when it is snowing, and this operation is run 24 hours a day, 7 days a week until the storm has ended. If conditions are particularly bad, two plows, a grader and a snow blower may also be employed. During normal conditions (i.e., no weather) just one snow plow is on patrol, and this is also planned for 24-hour-a-day, 7-day-a-week operations from roughly December to March. This patrol covers both Rt. 36 and Rt.44, as opposed to being dedicated solely to one route as is the case during a storm. Consequently, State Route 36 was traveled several times per day by maintenance staff during the winter months. No major changes to staffing levels on the pass have occurred in recent years.

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. R1 modified control is used when snow is sticking on each side of the pass, while R1 is used when snow pack is building at the summit of the pass. If there is heavy snow build-up in lanes that were just plowed after turning around, the R2 control is put into place.

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. No significant changes in terms of treatment materials have been made since 2009. Anti-icing chemicals, specifically Magnesium Chloride, are 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 or cinders, or a mix of the two. Ice Slicer™ is also employed as conditions warrant (this is a product that melts snow and ice and that is harder than salt and softer than sand). The application rates of these materials are about 250 pounds per lane mile but can vary depending on conditions.

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 Oceanic and Atmospheric Administration (NOAA) and Weather Underground is consulted before and during storms to plan and understand current and future conditions. Data from the ICWS RWIS sites is also used, with access to this information being made via WeatherShare.

From the perspective of maintenance forces, the only issue that the ICWS presents arises when pavement preservation/maintenance activities such as grind-outs and crack sealing are being carried out. During such operations, the location of the different in-pavement surface sensors require crews to skip over certain sections of pavement in the proximity of surface sensors. However, these are generally the spots that are most deteriorated and in need of maintenance. The upcoming rehabilitation project (2019-2020) will address this from a surface standpoint in the short term, as out-of-pavement ice detection will be added to the system, replacing those surface sensors

In general, the ICWS was viewed from a maintenance standpoint as being a good system that is providing timely warning to drivers. It was perceived as reliable in recent years, but it does present challenges to maintenance forces when conducting pavement preservation work. Aside from that, the system is viewed as beneficial to motorists.

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 researcher interviewed Jeff Worthington of the District 2 staff who has worked with the system for approximately the past three years. The following paragraphs present a narrative of information related to various aspects of the ICWS from an ITS Engineering point of view.

The initial question posed sought to record the current maintenance activities related to the ICWS. Maintenance activities related to the system at present include:

- Battery (charging capacity and water level) and charging system checks. Water is added or batteries are replaced as needed. There are two solar charging systems for the ICWS, one at the Fredonyer East RWIS site and the other at EMS sign location three (see Figure 1-1). All batteries were replaced at the Fredonyer East site during the 2013-2014 season, while the batteries were replaced at EMS sign location three during the 2014-2015 season. The charge controller at each of these locations has also had to be replaced at least once.
- Monitoring road surface sensors (RSS) and their alignment values. Due to aging and wear of these components, they require periodic adjustments to fine tune their sensing of conditions. Adjustments may be required once or twice a year per sensor. This adjustment involves typing in new base values to run the analog to digital conversion.

- Road surface sensor replacement. This occurs when the unit or cables become exposed or weakened due to pavement degradation. This past season (2014-2015), two cables with the West system required coverage with a patching tape to reduce exposure. An RSS unit also had to be replaced this past season for the Fredonyer East system in conjunction with grinding for pavement rehab.
- Monthly data collection. The system-related data, including status, sensor readings, speed data readings, and other information, are recorded on site, and monthly trips to the site are required to download that data. Once on-site, this requires one to two hours to collect the data and test the signs, as well as attend to any other maintenance items that the system may require.
- Sign checks. In conjunction with the data download visits, checks are made of each sign to see if any lights are burned out or nonfunctional. This is done by switching the signs to “manual” mode for inspection before returning them to “auto” mode for system-controlled operation.
- Periodic calibration of the RWIS. This requires a yearly certified, independent third-party calibration of these systems.

As these items indicate, the system requires vigilance to ensure it remains operational. Further, data records of its operation must be downloaded on-site; while cumbersome, this provides an opportunity to check the system and perform maintenance tasks as needed.

Several maintenance challenges have come up with the system over time. The solar battery charging systems work well when maintained, but components wear out and require replacement, as do the batteries. Related to the system controllers, the 3 volt battery that allows the controller to remember the date/time and files in the event of a power failure have a three year lifespan and are located in the EMS signs, requiring a bucket truck to replace when needed. A significant issue is related to the in-pavement RSS and wiring, which are affected by pavement condition and wear. Where pavement wear has occurred, sensors and wires can become exposed and prone to damage, requiring replacement. This in turn requires a lane closure to drill a new sensor hole, cut a new cable path and splice the cable to the roadside pull box. The SD cards used to collect data at the signs have differing lifespans and are not necessarily intended for use in a harsh environment. They require periodic replacement, but are an aging technology that may be discontinued at some point. Consequently, a stock of cards must be maintained to ensure replacements are available, as newer SD cards are not compatible with the technology at the site. Additionally, when a power failure occurs, it remains unknown until the next site visit for data downloads. This means that there is a need for balance between frequent site visits to catch these errors and infrequent visits that can result in losing large portions of data.

Different planned and recommended improvements have been identified for the ICWS. A pavement rehabilitation project is scheduled in 2017 for Fredonyer Summit, including a milling of the pavement at all locations where RSS have been installed. When this occurs, new Campbell Scientific RWIS systems will be installed to replace the existing SSI/Vaisala systems. The solar power systems will also be migrated to standard power distribution via the local utility. This will result in a more reliable power source for each system and lower maintenance needs. It will also provide more flexibility for the ICWS software, as the current system relies on vendor-supplied software. The changeover to the new RWIS will allow more intelligence to be built into the system and provide improved logging and notification capabilities back to the TMC and Electrical Engineering staff in Redding. This would include the immediate activation history of the signs, error notifications and remote data downloading. Finally, the new replacement RSS that will be installed would be located in a removable housing to reduce future replacement needs should the roadway surface require additional milling. One final, recommended improvement is the use of external, overhead sensors rather than in-pavement sensors to detect conditions. This type of sensor is being tested by the District at present but a final decision on its use for the ICWS has not been made.

Changes to the system that could be made to reduce maintenance include remote data collection/download. This would eliminate the need for physical site visits. Standard utility power would reduce the power issues that have occurred with the system. Finally, out-of-pavement sensors would reduce the need for in-pavement RSS units. The external sensors would need to offer the same data and reliability as existing RSS however. Regular calibration of the system/sensors is always necessary. In the future, more speed sensing capabilities may be employed at the actual curves to acquire speed data at the critical points of the system.

Recommended improvements for similar systems that might be considered for use elsewhere include the use of a reliable power source with a supply design that is simple. Off-site monitoring and data collection/recording would also be beneficial. A mechanism to monitor the system sensors remotely should also be considered.

Aside from being used in support of the different analyses presented in this report, the data collected by the ICWS is also being used by District 2 staff for different purposes. The current weather data for each RWIS is propagated through the system and shared on the internet, similar to the other RWIS sites in the district. The status of the signs (on or off) can be determined remotely by ScanWeb. Finally, the historic data logged by the system is used to verify that the logic that turns the signs on and off is working correctly.

The primary benefit provided by the system is that it is viewed to be saving lives. Local CHP officers in the area have provided good feedback to maintenance staff when seen in the field. As the results presented in the crash data analysis indicate, this perception is true. The system, while complex and requiring a vigilant attitude toward maintenance, has helped to reduce crashes on Fredonyer summit.

5.2.1. System Costs

For other agencies considering the deployment of ICWS systems, the costs involved in their acquisition and annual maintenance will be of interest. At present, such information is not readily available. To address this knowledge gap, Caltrans District 2 ITS Engineering staff have compiled information related to the costs of deploying such a system (initial equipment and installation costs) as well as recurring monthly costs (power and communications).

Caltrans District 2 ITS Engineering estimates that the overall cost for an ICWS (for one individual site, with two EMS signs at either end of a segment) at the present time would range between approximately \$520,000 and \$642,000, depending on the features employed in the system (for example, solar panels versus utility power), the site characteristics (terrain) and so forth.

In addition to the up-front installation cost, there are also recurring costs associated with the ICWS. These include electrical maintenance, engineering and support, utility power and telecommunications. Based on data from the Fredonyer ICWS sites from 2012 through 2014, a range of values associated with these aspects can be reported. Electrical maintenance costs ranged between $4,888 and $16,540 for the complete system during the period, while engineering and support costs ranged between $8,258 and $19,515. During the same period, utility power costs for one site ranged from $1,300 to $1,550, and telecommunications costs were a set price of $660 per year. These figures are intended to provide a better picture of the upfront and recurring costs an agency can expect when deploying an ICWS. However, all cases will be different, and as a result, costs are likely to vary as well.

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, Officer James Pecore of the Susanville CHP Area Office was contacted to obtain feedback on the ICWS from the perspective of patrol officers. Officer Pecore has been in his present position for the past 20 years, and frequently works on Fredonyer Pass. As a result, he has been working in the area since the initial work began on the ICWS.

Observations and perceptions of CHP regarding changes in speeds over the pass when the ICWS is on (particularly in the vicinity of the targeted curves) were that drivers do seem to be slowing down earlier in the season when the signs first begin to activate. However, as the season goes on and drivers become more acclimated to the signs, speeds return to their higher range. There has not been a noted change in the number of tickets issued on Fredonyer Pass during the winter since the system was implemented. There has not been a perceptible drop in crashes since the system became fully operational in 2009, at least from the perspective of CHP. From experience, the western curve is the location that sees the majority of crashes and spinouts - approximately 95 percent according to Officer Pecore.

In general, the system appears to be accurate in indicating ice conditions. The system appears to operate well and is accurate (to the extent that can be expected from a machine) in relation to roadway conditions. In line with this, Officer Pecore and his colleagues believe the ICWS is a good tool for warning non-local travelers of conditions in the area of the curves. However, local drivers were thought to have become complacent, particularly since the signs are activated for long periods of time during the winter months.

Additional thoughts and observations on the system included that it is a nice tool that has been adjusted over time to accurately notify drivers of the dangers that lie ahead. From experience, Officer Pecore has found that for every crash he has responded to in the area when the signs were activated, drivers were aware of the signs being on. The response he typically receives is “I knew the signs were on, but I didn’t know it was THAT icy”. In terms of potential modifications or improvements to the system, one thought would be having the signs flash when the speed sensor (radar unit) detects oncoming traffic. This might get drivers’ attention and help them to realize that there are potentially dangerous conditions ahead.

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 has been working well since its rebuild was completed. The data produced by the ICWS (pavement temperature and condition, as well as general RWIS data) is reviewed by maintenance forces, although traditional web-based weather forecast data is primarily relied on for operations. In general, the only issue ICWS presents to maintenance crews is the need to avoid work on portions of pavement in the vicinity of in-pavement sensors. Aside from that, the system is viewed as beneficial to motorists and provides timely information.

Feedback provided by ITS engineering indicated that the primary benefit provided by the system is that it is viewed to be saving lives. The system, while complex and requiring a vigilant attitude toward maintenance, has helped to reduce crashes. Tasks associated with the system include battery maintenance, sensor monitoring and recalibration/replacement, data download including radar speeds, and sign checks for function and condition. While these activities require a lengthy trip to and from the site, they are critical in making sure that the system is working properly. Potential future improvements to the system that have been identified or recommended include migration of the power supply from solar panels to standard distribution via the local utility and the possible use of external sensors to monitor pavement condition.

Finally, feedback provided by CHP indicated that when the ICWS is on (particularly in vicinity of the targeted curves) drivers seem to be slowing down earlier in the season when the signs first begin to activate. However, as the season goes on and drivers become more acclimated to the signs, speeds return to their higher range. There has not been a perceptible drop in crashes since the system became fully operational in 2009, at least from the perspective of CHP. In general, the system appears to be accurate in indicating ice conditions and it is a good tool for warning non-local travelers of conditions in the area of the curves. However, local drivers were thought to have become complacent, particularly since the signs are activated for long periods of time during the winter months.

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, specifically the analyses performed for clear, cold and dry/not dry conditions, 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. When day versus night mean speed data were examined, it was once again found that mean speeds were significantly different overall (0 mph) and differed by greater than 5 mph. 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. Of course, such 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 during most seasons. However, statistically significant mean speed differences greater than 5 mph were observed less frequently overall. 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. This reduction appears to be translating into a long-term safety benefit (i.e., reduced crashes in the curves). Bear in mind that the speed readings employed in this evaluation were collected at sign locations in advance of the curves targeted by the ICWS, and 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.

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 15%, which corresponds to an Accident Modification Factor of 0.85. As no other changes occurred along the study segment such as additional safety improvements or geometric changes, 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. As a result of reduced crash severities, the system was estimated to provide safety benefits of $1.03 million dollars per winter season during the after deployment study period (2008-2015).

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 winter maintenance, the ICWS has been working well since its rebuild was completed. The data produced by the ICWS (pavement temperature and condition, as well as general RWIS data) is reviewed by maintenance forces, although traditional web-based weather forecast data is primarily relied on for operations. In general, the only issue ICWS presents to maintenance crews is the need to avoid work on portions of pavement in the vicinity of in-pavement sensors. Aside from that, the system is viewed as beneficial to motorists and provides timely information.

Feedback provided by ITS engineering indicated that the primary benefit provided by the system is that it is viewed to be saving lives. The system, while complex and requiring a vigilant attitude toward maintenance, has helped to reduce crashes. Tasks associated with the system include battery maintenance, sensor monitoring and recalibration/replacement, data download including radar speeds, and sign checks for function and condition. While these activities require a lengthy trip to and from the site, they are critical in making sure that the system is working properly. Potential future improvements to the system that have been identified or recommended include migration of the power supply from solar panels to standard distribution via the local utility and the possible use of out-of-pavement sensors to monitor pavement condition.

Finally, feedback provided by CHP indicated that when the ICWS is on (particularly in vicinity of the targeted curves) drivers seem to be slowing down earlier in the season when the signs first begin to activate. However, as the season goes on and drivers become more acclimated to the signs, speeds return to their higher range. There has not been a perceptible drop in crashes since the system became fully operational in 2009, at least from the perspective of CHP. In general, the system appears to be accurate in indicating ice conditions and it is a good tool for warning non-local travelers of conditions in the area of the curves. However, local drivers were thought to have become complacent, particularly since the signs are activated for long periods of time during the winter months.

6.2. Challenges

During the course of this work, a couple of challenges were encountered. First, the radar data collection equipment employed to collect vehicle speeds were located at each EMS sign location and 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

A number of recommendations for future work and monitoring are advisable. First, while the crash data analysis completed during this work employed a longer period of time, it would be advisable to revisit this analysis at a future date, perhaps at approximately the ten year point post-deployment. 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.

Coincident with planning for future safety (and speed) evaluations, it is recommended that Caltrans District 2 continue to maintain records of manned chain control levels. These records can consist simply of saved .pdf files from the chain control report log. Such 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. To provide perspective on how long this data should be saved, another evaluation of the system could be considered at the ten year point following deployment.

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. This aspect is particularly of interest given the observations of CHP staff in the field, which indicate that speeds appear to increase as the winter season goes on. It is possible that speeds will also begin to climb the longer the system remains deployed (in terms of years). Conversely, as the system remains deployed over a longer period, drivers may come to trust its indications of icy roads and the speed reductions observed here may remain somewhat constant.

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 (e.g., permits to place data collection equipment and/or run power to that equipment on Forest Service lands). The inclusion of such speed measurement capability is envisioned during the upcoming pavement rehabilitation project (2019-2020).

The speed data collected by radar during the course of this project was aggregate and did not classify vehicles by their type. 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. If possible for future work, data should be collected by equipment which is capable of classifying and binning vehicles by type.

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. 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.

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