Northern California Vehicle Infrastructure Integration Case Study

by

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1. Introduction

1.1. The Background of this Project

The area comprised of CALTRANS District 1 is the northwestern corner of California and consists of the counties of Humboldt, Del Norte, Mendocino, and Lake. The geography is primarily coastal, coastal hills and low mountains. The largest city is Eureka (pop. 27,000) located on the coast approximately 100 miles south of the Oregon border. 50 miles north of Eureka is the tourism destination of Redwood National Park. The most important highway in this area is US 101, which parallels the Pacific coastline from southern California to near Seattle. US 101 is primarily a four-lane highway with short lengths of two-lane. The remainder of the roads are mostly two-lane rural highways carrying a mixture of local residents, tourists, and fleet traffic. There is a significant component of large trucking, with many trucks carrying logs and lumber in support of the area's lumber industry.

This project builds on two foundations, the California/Oregon Advanced Transportation Systems (COATS) project and the independent development of technologies for vehicle-infrastructure integration (VII) systems. The COATS project investigated travel challenges in the two-state California-Oregon border area and is testing advanced technologies of various kinds to address those challenges, primarily on multiple-lane highways. The development of VII systems is providing technologies for direct communication of hazards and potential responses between the roadway infrastructure and the vehicle. These two foundations will be described in more detail in the following sections.

1.1.1 The COATS Project

The transportation corridor connecting northern California with central Oregon provides significant challenges to the transportation engineer and the traveling public. The terrain is mountainous, a large percentage of the roadways are narrow, rural two-lanes. Even the major roadways (US 101 and I-5) can provide challenging conditions for travelers.

Weather and geography are the sources of many of the transportation challenges. Travelers throughout the corridor must contend with diverse and rapidly changing weather conditions including snow, high winds, fog and heavy rain. The combination of varied driving conditions and abundant off-road, commercial and recreational traffic produces an immediate and expanding need for increased traffic safety measures and information dissemination techniques.

The two-state area contains transportation links vital to the region’s economy and commercial industry. Numerous primary and secondary routes serve commercial vehicles destined for urban centers throughout the West.

The overarching goal of the COATS project was to provide a showcase for advanced technologies in order to address these problems. The goals of COATS were as follows:

- Identify the transportation and information needs within the study area;
- Determine ITS solutions that are beneficial, cost-effective, and implemental for deployment within the study area on the basis of the identified needs;
- Identify, design and deploy initial, small-scale “early winner” projects with existing funds on a multi-year basis to test the feasibility of rural ITS;
- Develop a Strategic Deployment Plan that describes a strategic approach for implementing rural ITS strategies on a larger scale, with an emphasis on integration and expansion of future ITS components within the study area based on evaluation results; and
- Prepare proposals and secure Federal funds to implement Rural Model Deployment Initiative projects.

Another way of describing the COATS project is that it is a combination of ITS planning, through the creation of the Strategic Deployment Plan, and ITS demonstration, through projects like the “early winners.” The demonstration aspect of the COATS project continues after COATS project funding is exhausted, with the COATS Showcase program. This effort provides funding for demonstration and evaluation of identified technologies, consistent with COATS goals and objectives, in the COATS study area.

1.1.2. Vehicle-Infrastructure Integration Systems

For the purpose of this project, five specific functions were initially selected for primary consideration. These were:

- Longitudinal Warning: Functions related to sensing and maintaining a safe following distance between vehicles in the same lane.
- Lateral Warning: Functions related to sensing and correcting unsafe deviations from the selected driving lane.
- Intersection Collision Warning: Functions related to sensing on-coming vehicles on an intersecting crossroad and alerting the driver when it is safe/unsafe to enter the intersection.
- Vision/Visibility Enhancement: Functions related to supporting the vision of the driver during conditions of degraded visibility resulting from darkness, weather, glare, or other factors.
- Safety Readiness: Functions related to alerting the driver concerning potential safety problems including obstacles, infrastructure problems, or issues of driver fitness.

1.1.3. Project Summary

Vehicle Infrastructure Integration Systems are Intelligent Transportation Systems (ITS) that integrate infrastructure, such as traffic and traveler information technologies, with in-vehicle advanced vehicle display, control and safety systems. These cooperative solutions are intended to address short-term safety and operational challenges, as well as the more long-term complex transportation challenges - as in the areas of safety, congestion, pollution, and land use - that conventional ITS or traditional transportation cannot address.

Vehicle Infrastructure Integration Systems are intended to bridge the gap between advanced vehicle control systems and infrastructure communications and information systems. These systems require both conventional transportation planning and the planning needed to integrate new technologies into the existing system.

The Vehicle Infrastructure Integration Systems are the next generation of Intelligent Transportation Systems. The goal of the VII Case Study is to recommend applications and consider implications of Vehicle Infrastructure Integration Systems in a rural environment. The research is focused on developing applicable advanced technology solutions that will assist fleet operations and would ultimately increase safety and improve operations of the transportation system in northern California. The research will examine principally the two-lane rural highway (non-interstate) system. While many emerging VII systems provide some degree of automated vehicle control and the ability of a computer to take over control of the vehicle from the driver when indicated, this technology is beyond the scope of this project. The scope of this analysis was limited to systems that provide supplemental information to the vehicle driver.

This project is conducting research and development that will lead to testing and deployment of Vehicle Infrastructure Integration Systems concepts that solve rural transportation challenges. As it is difficult to initiate or influence the deployment of technologies on light duty passengers vehicles, the opportunities for research, development, testing and potential deployment lie in partnering with a fleet owner/operator or in developing infrastructure systems that complement emerging in-vehicle technologies. Examples of fleets include trucking, transit, law enforcement, and emergency vehicles as well as vehicles that operate and maintain utilities like power, communications, or transportation facilities. Emerging technologies that this project may interact with include in-vehicle traveler information, where one challenge will be the ability to provide reliable, real-time highway related information such as local weather or roadway surface conditions.

1.2. Description of the problem

Initial activities by the National Automated Highway System Consortium (NAHSC) were focused on urbanized areas. However, a need exists to investigate the applicability of advanced transportation technology in rural settings. Technology applications have primarily focused on problems associated with urban traffic congestion; with secondary considerations related to safety, air quality and energy conservation. These areas are also of concern to the rural transportation provider; however, the primary focus of the rural transportation provider is to improve safety.

There are many safety benefits potentially realized through the application of Vehicle Infrastructure Integration Systems to the existing transportation infrastructure, such as through advanced driver warnings. It is estimated that if a driver were warned of an impending collision one half second earlier, 50 percent of rear-end and intersection crashes and 30 percent of head-on crashes could be avoided. If an additional second is provided to the driver, 90 percent of all crashes could be avoided. Experts estimate that advanced transportation technologies will potentially save 11,500 lives, 442,000 injuries, and $22 billion in property damage nationally by 2010.

1.3 Vision

The vision for this VII Case Study will be a Vehicle Infrastructure Integration System that can evolve as the roadside and vehicle safety systems are implemented, communication coverage increases, fleet technology improvements migrate to a rural environment, and fleet managers understand the application of technology to their specific needs. It is envisioned that the Vehicle Infrastructure Integration System that may be used in this project would evolve from spot application to information assistance.

It is expected that this project will focus on technologies that exchange information between the vehicle and roadside infrastructure and may provide, at most, some very minimal level of assisted vehicle control based on this exchanged information. This project reviewed technologies that can be implemented in the near term, are beneficial in the rural environment, and can be implemented in a fleet of vehicles. An example would be the use of remote weather information systems and dynamic message signs. While the general public may use this information for safety at this time, the information is not transmitted to in-vehicle systems but directly to the vehicle drivers via their eyes .

The Rural Fleet Application Case Study would utilize targeted fleets to demonstrate the benefits of Vehicle Infrastructure Integration System. The Vehicle Infrastructure Integration System would provide for increased benefits over roadside infrastructure (e.g., signs) that can only provide information to the driver and not to the vehicle. The VII Case Study might utilize roadside infrastructure to transmit a signal to the vehicle (for example, through a smart license plate) that would automatically provide hazard information to the driver. Partially automated communication of travel information between vehicles may also be included.

1.4 Why California District 1?

This project is focused on the California portion of the California Oregon Advanced Transportation System (COATS) region and will build upon findings from that research. Because of the project's rural focus Caltrans Division of Research and Innovation (DRI) and WTI chose to emphasize deployment on non-interstate highways. COATS was a study that focused on rural intelligent transportation systems in the Northern California and Southern

Oregon regions. For the present project, Caltrans and WTI wished to narrow the geographic area to northern California and focus on one district to minimize logistical challenges to help minimize overhead costs, reduce the size of the advisory committee, and reduce travel costs.

WTI chose to concentrate on District 1 for the VII project. District 1 appeared to be better suited for VII deployment than District 2 in three of the four focus areas:

- District 1 has a higher density of safety challenges per mile of roadway
- District 1 has a higher density of existing or short-term planned ITS elements
- District 1 has a higher frequency of road closures per mile of roadway
- District 2 has a lower population density

The larger and denser population of District 1 would favor District 2 as the choice for a rural environment in that category. But both districts are considered rural in comparison to areas such as San Francisco and Los Angeles, which have population densities ranging from 1,000 to 3,000 people per square mile.

Nine categories of safety challenges were identified by the COATS project, with six of them selected as relating to this project. The Intersection Safety challenge was tabulated as a count of intersections and the remaining were tabulated based on mileage of roadway where those types of dangers were prevalent. A logical way was needed to compare the number of challenges in each district because of the difference in size. This was done by comparing the total miles of hazards to the total miles of rural highways for each district, excluding Interstate 5. A larger number would show a higher number of hazards per mile of roadway in the district. Table 1 shows the number and miles of challenges identified in the COATS project for each district. Based on this comparison District 1 has a higher density of safety challenges than District 2.

Table 1: Challenges for Northern California VII Project

Challenge	District 1	District 2
Intersection Safety (number)	1	0
Narrow Roads (mi.)	487.3	124.3
Inclement Weather-Road Surfaces (mi.)	0	87.2
Inclement Weather-Poor Visibility (mi.)	102.5	0
Animal Collsion (mi.)	0	67.8
Driver Fell Asleep (mi.)	174	91
Total Challenges Road Miles	***764.8***	***370.3***
Road Miles Per District	***620***	***1258***
Mile Challenges per mile of road in district	***1.23***	***0.29***

The ITS elements that will be in place at the time of deployment of the *NCVIIS* possibly can be used in conjunction with *NCVIIS* elements to increase the effectiveness. Therefore, the count and density of existing elements and these planned for short-term deployment is a factor in choosing the district for *NCVIIS* deployment. Figure 1 shows the locations of short-term planned and existing ITS in the region, excluding Interstate 5. A summary of ITS in the region shows District 1 to have 36 locations and District 2 to have 13.

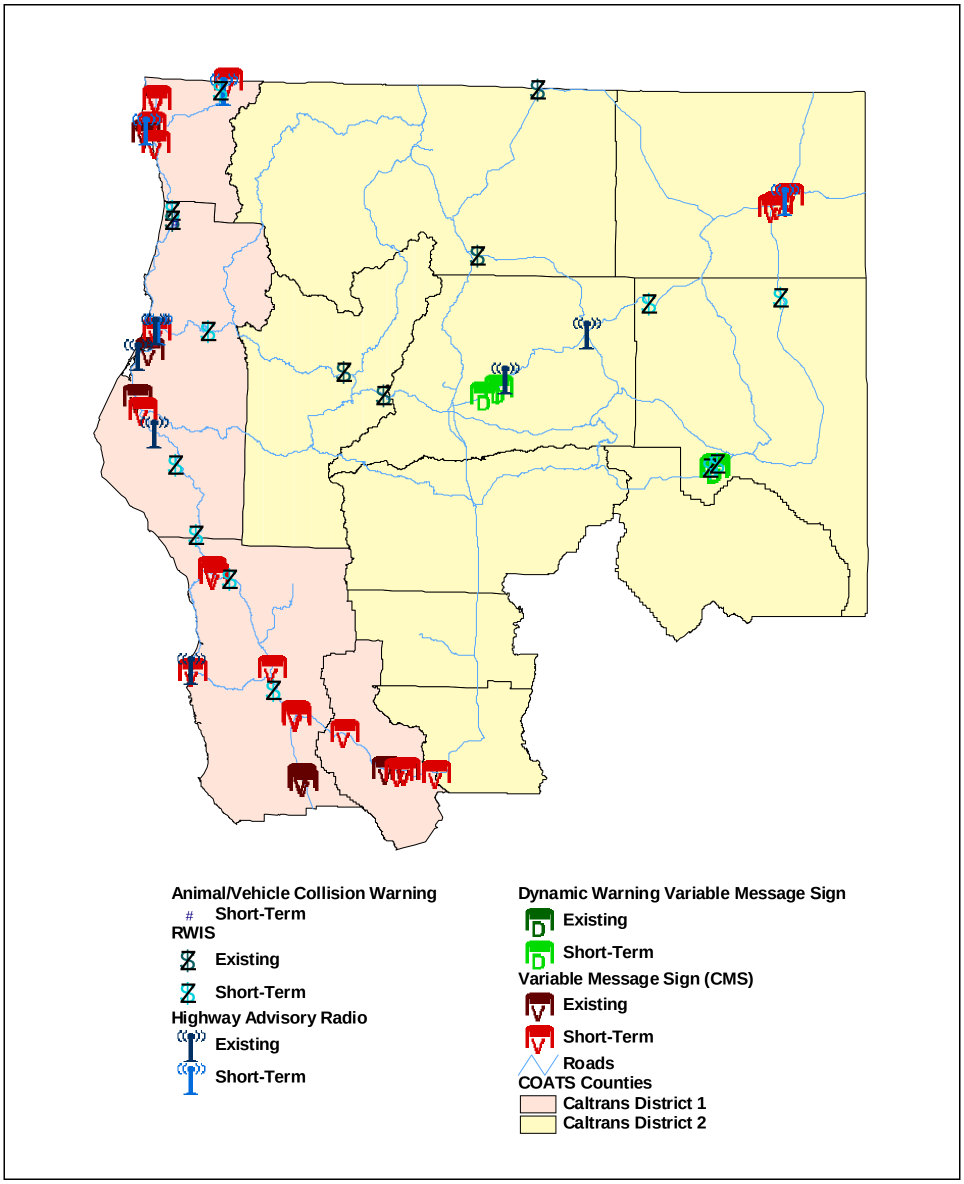


Figure 1: ITS in the Northern California Region

Numerous accidents and accidental delays could be avoided or minimized by providing information to travelers about closures and alternate routes. Table 2 shows data collected by the COATS project over different time periods. The information for District 1 was collected from February 1995 through December 1997, a 34 month period. The information for District 2 was collected from January 1998 through September 1998, a nine month period. Because the time periods of data collection differed, the totals were normalized to get a per year average for each type of closure along with totals. The number of closures could be partial or full, and the length was for the total duration of the closure. Per mile comparison was needed between the districts because of differentiation in size. The higher the number of closures or days, the greater amount of reduced traffic flow per mile of roadway per year.

Table 2: Road Closures for Northern California VII Project Area

	District 1				District 2			
Reason for Closure	Number of Closures (34 mo.)	Number of Closures per year (closures*12/34)	Days of Closure per year (34 mo.)	Days of Closure per year (days*12/34)	Number of Closures (9 mo.)	Number of Closures per year (closures*12/9)	Days of Closure per year (9 mo.)	Days of Closure per year (days*12/9)
Flood	62	21.9	217.7	76.8	6	8.0	0.8	1.0
Object on Road	45	15.9	40.0	14.1	8	10.7	0.0	0.0
Slide	181	63.9	1718.7	606.6	18	24.0	70.9	94.6
Vehicle Crash	78	27.5	107.8	38.0	89	118.7	258.1	344.1
Weather (Snow)	0	0.0	0.0	0.0	18	24.0	11.6	15.5
Construction	48	16.9	22.4	7.9	6	8.0	170.7	227.5
Fire	7	2.5	1.2	0.4	0	0.0	0.0	0.0
Maintenance	28	9.9	169.3	59.7	0	0.0	0.0	0.0
Other	15	5.3	9.3	3.3	0	0.0	0.0	0.0
Total		***163.8***		***806.9***		***193.3***		***682.8***
Road Miles	***620***				***1258***			
Totals (closures or days/mile/year)		***0.264***		***1.302***		***0.154***		***0.543***

2. Literature Review

The objective of this chapter is to provide a background to the research. A review of existing literature on vehicle-infrastructure integration systems was necessary to establish a baseline for further research and implementation. For the purpose of this project, five specific functions were initially selected for primary consideration. These were:

- Longitudinal warning/control
- Lateral warning/control
- Intersection collision warning/control
- Vision Enhancement
- Safety readiness

2.1. Longitudinal Warning/Control

Longitudinal warning/control is being researched by several automobile manufactures: primarily BMW, Mercedes Benz, and Porsche. This research concentrates on spacing distances from one vehicle to another. If a radar sensor detects a car or other possible obstacle in the lane in front, the driver will be alerted. Driver performance research in a driving simulator demonstrated a major reduction in rear-end crashes when the driver is warned of a following distance of less than two seconds. The BMW system allows the car to slow when it gets too close and speed up to follow at the right distance if it is operating on automatic mode. Many longitudinal systems have automatic braking if the vehicle is approaching another to close. The system appears to be adaptable to a rural environment, in which radar sensing could also be used for vehicles, animals, and objects on the roadway. It is estimated that 9% of accidents that involve injury can be avoided with the driver assistance system.

2.2. Lateral Warning/Control

According to NHTSA, more than 43% of fatal crashes involve a lane or roadway departure. Roadway departures are the larges cause of serious accidents by trucks. Lateral warning and control systems detect the position of the vehicle within its driving lane and provide warnings or control assistance when a lane departure is imminent. Such systems may prevent run-off-road crashes, sideswipes, or head-on crashes when a vehicle leaves its intended lane due to visibility problems, driver distraction, a fatigued or complacent driver, or entering a curve at too great a speed. These systems may use magnetic detection, laser technology, visual image processing, or global positioning system (GPS) technology to determine the vehicle's lane position and lateral movement within the lane.

Bantli did experiments using magnetic tape to allow snowplow operators to remain on the roadway when visibility would not allow them to (Bantli 2000). During snowstorms, visibility can be reduced significantly, which affects the speed of the plow trucks. Minnesota, Mining, and Manufacturing (3M) developed a magnetic tape that the Minnesota DOT uses on highways conjunction with magnetic detection equipment on snowplows. The tape has been shown to increase the comfort level of the plow operators by alerting them when their vehicle starts to drift of the highway during low visibility areas.

During the 1999 Western Snow and Ice Conference in Greeley, Colorado, many of the snowplow operators took a survey to see how they felt about the magnetic guidance system (Bantli 2000). On a scale from 1 to 10, with 1 being no improvement and 10 being significant improvement, the operators gave a 7.98 to improved personal safety. They also gave a 6.3 to improved public safety, 5.7 to improved level of service for the road, and a 5.2 for improved maintenance and operations. Eighty-nine percent of the operators thought operations would benefit during white outs, and 78% recommended the use of magnetic guidance systems.

The public can also benefit from these systems (Bantli 2000). Because snow can be removed quicker, the public is allowed safe access for highways to travel on. The use of the magnetic tape can reduce costs by lowering accidents and increasing efficiency by allowing the driver to have his entire plow on the road. This in turn will reduce money being spent on snow removal, lost work time, and delayed commerce transactions. The magnetic strips can also come in a white or yellow color, so they can be used to replace the existing lines on a highway. They can also be placed underneath two layers of asphalt, which allows them to last as long as the existing roadway surface.

Numerous systems based on visual imaging technology are reaching the market. The Iteris™ Lane Departure Warning System consists of a small camera, computer and software that tracks visible lane markings, predicts the path of the vehicle in relation to the lane markings, and sends a warning when a lane departure is predicted. The warning (virtual rumble strip) may be in the form of an audible alarm simulating a rumble strip or it may be in the form of vibrations in the driver seat.

A number of approaches have been proposed for the algorithms used to trigger the lane departure warning. A real rumble strip consisting of grooves milled into the pavement provides the warning when tires roll over them. Therefore, the vehicle must have already departed the lane. With a computerized virtual rumble strip, it is possible to predict the future path of the vehicle and to trigger the warning when the lane departure is imminent but before it actually occurs. The form of the prediction algorithm has been the subject of research. Pilutti and Ulsoy (2003) at Ford Research Laboratories compared the efficacy of "fixed" rumble strips at a defined distance from the road edge with two computer calculated prediction algorithms. "time to lane crossing" (TLC) and a fuzzy logic-based "variable rumble strips" (VRBS). The two computer-based algorithms provided similar performance but VRBS was found to be superior because it required less computing power.

2.3. Vision Enhancement

In California, Partners for Advances Transit and Highways (PATH), was formed in 1986 to incorporate ITS protocols. Currently, one of their projects uses magnets in the center of the lane to inform the vehicle it is following in the right path (PATH). The magnets are placed every 1.2 meters, and can give accuracy of 5 mm laterally and 5 cm longitudinally. Rain or snow does not affect how the magnetic works with relationship to the vehicle. This system is also cost effective. Magnets can be installed in the roadway for $10,000 per lane mile, while rebuilding the roads would cost $100 million per road mile (Bryant). This process can be used for automatic steering control, lane departure warning, guidance for snowplows, transit bus docking, and automated vehicle location.

A project by MnDOT, the Minnesota Guidestar project, is being used to create an environment that will help the driver by vision enhancement. During a snowstorm, visibility is limited but with the use of magnetic tape and heads up displays (HUD) in the vehicle, the driver's ability to see the road boundaries is increased. This will give the operators a higher comfort level by informing them when they are on the correct pathway. One project in Minnesota is the Snowplow Intelligent Vehicle Initiative (IVI). This project requires magnetic tape down the center of the road, which allows the snowplow operators to know they are still on the road (Snowplow IVI hwy19). It also includes front and rear radar. The front radar informs the driver about obstacles in the pathway, and the rear radar alerts them of traffic approaching them from the rear. The Snowplow IVI is also being tried on Highway 101. This project uses differential GPS and radar to see obstacles and roadway boundaries (Snowplow IVI hwy101). It also has a HUD on the window which snows where the actual road boundaries are. Another part of the Minnesota Guidestar project is the Highway 7 Field Operation Test. This project uses lateral guidance and collision warning to inform snowplows, ambulances, and State Patrol cars, of possible problems (IVI). The technology be used is DGPS, magnetic pavement marking, radar, warning devices, and a HUD on the windshield. The purpose of this project is to determine human factor considerations.

Every year almost 15,000 people die in single vehicle rollovers (Pomerleau, 1996). Almost 70% of these deaths occur on rural roads. Because most of these roads are not going to be updated in the near future, some sort of vision system must be implemented to reduce these numbers. One possible solution, RALPH (Rapidly Adapting Lateral Position Handler), is being tested to help with this problem (Pomerleau, 1996). RALPH consists of three steps: determining images, determining road curvature, and making sure the vehicle stays in the middle of the road. The last two steps send a steering command to a special steering motor that can control the direction the vehicle travels. RALPH has been tested in a lab, and test tracks, and on the road. The results of the testing indicate that a vehicle position can accurately be estimated as well as the curvature of the road. The road test consisted of 2,850 miles from Washington D.C. to San Diego. The test was done during normal driving stages: night driving, during a rainstorm, during sunset, etc. RALPH controlled the vehicle for 2,796 miles, or 98.1%.

Kaneko did testing in Japan to determine how useful millimeter wave radar and closed circuit TV (CCTV) were in detecting objects, vehicles, and pedestrians on the roadway. Kaneko did a survey of 1574 drivers, and during the winter situations, many of them were almost in accidents on flat areas, intersections, and curves (Kaneko, 2001). They also said that the most reduced visibility occurred in flat rural areas.

All of these road conditions occur frequently in a rural environment. Kaneko determined that millimeter wave radar is an excellent way to measure distances and speed, but it does not identify objects adequately (Kaneko, 2001). This is because the waves have a narrow beam width. The millimeter wave radar can effectively capture a vehicle at 200 to 250 meter, and is effective in a flat area. The vehicles that receive the radar also can send a message to the trailing vehicles alerting them of any dangers ahead. In contrast, the CCTV can detect objects in a wider range, but at larger distances its effectiveness decreases. These tests showed that the combination of the two devices gives the driver additional time to slow down when approaching and passing obstacles on the road. The decreased vehicle speeds should result in fewer accidents on that section of roadway.

A system test was conducted on an intersection of a national highway (Kaneko 2001). At the intersection, a millimeter wave radar, along with a road monitor camera, was set up to determine when cars passed by, if cars stopped at the intersection, and if cars were slow moving. The information obtained was displayed on a variable sign board 200 m before the intersection. The radar proved to successfully detect 99.2% of the vehicles correctly. All of the information was displayed correctly on the sign board. Overall, the test was considered to be a success.

Another test was done to determine how drivers would respond to warning information. The test was located at the Ishikari Snowstorm Experiment Site of CERI from February 4-13, 1998 (Kaneko 2001). A board that resembled a car was set up on an icy roadway. Two tests were run, one with the drivers not warned about the can, and one with the drivers being warning by flashing lights. The results show that when the drivers were informed of the danger, they avoided it easily. This eliminated much of the excessive slowing or sudden braking.

Because of the effectiveness of the millimeter wave radar and using message boards to warn drivers, the Smartway Promotion Conference of the Ministry of Construction has proposed to use this technology on the second Tomei/Meishin Expressway in 2003 and regional development in 2004 (Kaneko 2001).

2.4. Intersection Collision Warning/Control

One focus of the Infrastructure Consortium of the United States Intelligent Vehicle Initiative is the development of intersection collision avoidance systems. The Infrastructure Consortium consists of state DOT’s from California, Minnesota, and Virginia. The members agreed that the deployment of such infrastructure could be in place by 2010. The rural application of this type of infrastructure is to develop systems that can be used with signals and stop signs to reduce accidents.

Maine DOT has used intersection collision avoidance to install an interactive warning system that informs motorists when it is safe to proceed. The intersection of US Route 201A, Sophie May Lane, and River Road in Norridgewood creates a great hazard because drivers have difficulty seeing traffic in all directions because concrete arches from a bridge obstruct their line of sight (News). The system alerts drivers stopped at stop signs of oncoming traffic from either direction on US Route 201A. Once a vehicle stops at the stop sign, the system is activated and a sign in front of them lights up for two seconds to indicate the system is working. If a vehicle is approaching, the sign will indicate a flashing car outline that indicates which way the car is traveling. The driver must still use his judgment to determine when it is safe to travel through the intersection, but this system definitely aids in determining when traffic is approaching. It is not known at this time the effectiveness of the sign, but currently Virginia and Georgia are using systems similar to this one. The installation cost for the sign and all of the needed equipment was around $36,000 (News).

2.5. Safety Readiness

Numerous ITS technologies have been prototyped and implemented to increase the safety readiness of the driver by warning of unexpected obstacles. Wizard CB, a system developed for PennDOT has been extensively tested for warning of upcoming work zones. A prerecorded message with the warnings is transmitted at regular intervals on citizens band radio, commonly monitored by truck drivers and other long-haul drivers. The system has an operating range of up to 4 kilometers.

The Safety Warning System™ transmits warning messages on microwave frequencies used by law enforcement radar systems. The signals are decoded and displayed by radar detectors used by many drivers. The SWS transmitters may be mobile (mounted in police cars or school busses) or may be barrel-mounted along the road. A menu of 64 different messages may be transmitted to radar detector-equipped vehicles. The system has a transmission range of approximately one kilometer.

Many auto manufactures (Mitsubishi, Mazda, Nissan, etc.) are doing research to develop a system that can detect a drowsy driver. This research has been focused on sensing the driver's eye movements and monitoring the vehicle for drifting out of the current lane. The detection of eye movement would be monitored using a camera, which would sense when the eyes have closed for too long (Attention). This would trigger some sort of warning, possibly an audio warning or vibrating seat to alert the driver. If the vehicle already has lateral warnings/control, the driver would be notified when the movement is starting to go out of the normal path. The same type of warning would be used to alert the driver when this occurs. An Australian study (Hartley, Horberry, Mabbot & Krueger, 2000) surveyed the technologies available for detecting and alerting fatigued and drowsy drivers.

2.6. Driver Acceptance

The acceptance of vehicle highway cooperative systems for drivers is related to the ease of use and the recognition of the information for use. The following studies were done to show driver reception of the data and how the information was processed.

Overall, there are many ways that a rural area can benefit from the types of ITS envisioned to be deployed in this project. These will include enhancing the safety of the public and improving emergency response times (Hill). They will also provide road and weather information to travelers, and make the public transportation more accessible and available.

De Vos explored the effects that automated vehicle guidance (AVG) has on driver comfort when dealing with spacing (De Vos, 1997). Even though AVG is not going to be implemented in this project, it needs to be taken into consideration when dealing with installation of ITS projects into rural areas. This particular test was used to monitor people's comfort level depending upon the headway, or spacing, of their vehicle with relation to other vehicles. Drivers were tested three times: once using manual control, AVG with a fixed headway, and AVG with a variable headway. Drivers would notify their changes in comfort level by pushing or pulling a lever. The level of comfort for the drivers at different speeds was higher with a greater headway than a lower one. AVG also increases capacity over a stretch of road because the vehicles are closer together (De Vos).

This experiment can be implemented into rural areas because there is a larger amount of headway than in an urban area. With the acceptance of the driver, AVG could be used to guide a vehicle in a rural area. It is estimated that 90% of accidents are driver related (Driving); so helping the driver in accident situations would help lower accident rates. All over the world, people are trying to implement AVG. In Europe, some vehicles have already been installed with fully automatic capabilities and are being tested (De Vos 1997). In the US, a precursor system analysis (PSA) on automated highway systems has been initiated, and the National Automated Highway System Consortium (NAHSC) was formed.

Gish investigated response time of drivers at night using vision enhancement systems (VES). The test consisted of a course laid out on an airstrip with targets: deer, pedestrians, a gray board, and a vertically striped board on the side of the road (Gish 1999). The drivers were to drive the course with verbal instructions to follow. The response of the drivers to the signs was recorded using the driver's eyesight. The test was then run again using VES. The two experiments showed that a greater distance for object detection was observed when using the VES. For younger drivers, the test revealed that target observations increased 100 ft to 200 ft, depending upon the size of the object, when the VES was used. The older drivers were more uncertain and less positive about using the VES. This test could have some small error because stationary targets were used instead of moving, a small sample size was used, and there were no practice trials. These factors may have affected the response time of certain drivers because of the unfamiliarity with the equipment, especially older drivers.

Lloyd experimented with collision avoidance by using a haptic brake warning system at stop sign intersections. 26% of all accidents occur at intersections, and 46% of these are stop sign related (Lloyd 1999). This study showed that drivers respond to intersections by depressing the accelerator nine seconds before entering the intersection, and applying the brakes two seconds later. The timing of the intersection warning system is important because if the driver is alerted too early, the driver will ignore the warning. If the warning is too late, the driver will not have time to react.

Three types of warning systems were used to evaluate intersection collision avoidance systems: auditory, visual, and haptic (Lloyd 1999). Each system has certain advantages and disadvantages, but the haptic system was the best fit for most situations. It did not require the driver to use sensory receptors for detection. This is valuable because if the warning is auditory or visual, the driver still has to recognize that an action needs to be done, but the haptic system performs it for them. It may use brake pulses to notify the driver that he/she needs to slow down, and at the same time it slows the vehicle. The haptic warning system has a low attention demand, is easily detectable, and can be used to reduce the number or read end collisions. One technological issue right now is the fact that haptic systems are not widely available in automobiles right now. One positive issue about the haptic brake system is the price. Currently, the cost to install is $2,000, which is reasonable considering the benefits. In the future, brakes could be triggered by wire, which would decrease the cost of the haptic system 1/100. This research relates the use of stop signs and controlled intersections, which are more frequent in a rural environment than in an urban. Haptic warnings have also been recommended for lane departure alerts. Vibrating pads on either side of the driver's seat are used to warn of a departure to the side that is vibrating. Researchers report that drivers instinctively turn away from the direction of the vibration. In addition, the vibrating pad is not intrusive to the passengers as an auditory alert might be.

There are several different types of technology that can be used for collision avoidance systems. Some of these technologies are multiple-beam radar system, a geographical information system (GIS), and a global positioning system (GPS) (Lloyd 1999). The GIS-GPS data is used to detect upcoming intersections, identify traffic requirements at the intersection, and determine the vehicle’s distance to the intersection. This data can then be used to determine if the vehicle is going to stop before entering the intersection, and provides a warning to the driver if not. Radar systems track the location and speeds of traffic on the primary road and provide a signal to the vehicle entering from the secondary road when it is safe to enter and merge into the traffic flow.

3. Identifying the Challenges

Several methods were used to identify transportation challenges and hazards in the selected geographic area. These included a detailed accident epidemiological analysis of three years of traffic accident data in Caltrans District 1 that identified a number of clusters of accidents. In addition, recommendations were made by a technical advisory panel consisting of Caltrans District 1 engineering, fleet management, and safety staff members. The findings of these investigations are summarized in the following sections.

3.1. Crash Data

To identify which transportation challenges may benefit from AITS applications, researchers examined crash-related data to determine the magnitude of each problem. Details of the analysis and results were presented in a report by Ballard (2003). Then, based on consultation with our Caltrans District 1 advisory committee, two of the segments were selected for more detailed analysis of potential countermeasures. This section describes the data analysis process.

Crash rates helped identify segments in the district that had potentially atypical crash challenges, meaning locations that experienced unusually high occurrences of crashes relative to the volume of traffic traversing that segment of road. Typically, crash rates are good indicators of areas where crashes occur as the result of recurring contributing circumstances. Locations with atypical crash rates compared to the rates on other Caltrans roads across the district were tagged as a high accident location (HAL) and analyzed for a crash trend. The crash analysis and HAL description will aid in prioritizing the challenges and establishing specific locations for implementing AITS applications.

3.1.1. Method

All reported crashes on District 1 highways for a three-year period from 1998-2000 were analyzed. All details for these 6,627 crashes were exported from the Caltrans TASAS database. The severity of these crashes is shown in Figure 1. For this study, crash rates were determined for each half-mile segment along the corridor. Additionally, crash rates weighted by their severity were determined for each half-mile segment. Based on these rates, potential high accident locations were determined. These locations were then analyzed to determine what, if any, crash trends existed. These segments were thought to have the best chance of realizing the greatest benefits from AITS safety countermeasures.

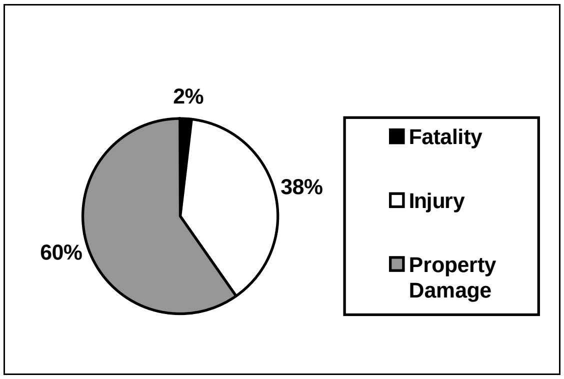


Figure 2: Crash Severity in District 1

For each of the high accident locations, researchers created a location summary. The statistics for the location are summarized. Then researchers reviewed the Caltrans video postmile logs to understand the characteristics of the road. Key snapshots of the log are included in the location summary. Finally, a geographic information system (GIS) was used to map the locations, depicting the road geometry and the locations of all crashes.

Table 3: Postmiles of Crash Locations for Sample Site

Property Damage Only	Injuries	Fatalities
7.25	7.07	8.4
7.53	7.17	
7.54	7.55	
7.54	7.57	
7.58	7.58	
7.74	7.64	
8.26	7.74	
8.27	7.79	
8.28	7.89	
8.47	8.25	
	8.26	

The Caltrans traffic volume database has the same traffic volume for the entire length of the segment being analyzed, as shown in Table 2.

Table 4: Average Annual Daily Traffic for Sample Site

Route	From PM	To PM	AADT
199 DN	5.9	14.64	2900

With the information in Table 1 and Table 2, the simple crash rate and the severity rate can be calculated. These calculations, shown in Table 3, were made for half-mile segments, with each row starting 0.1 mile from the previous row's start. Columns A, B are given. Columns C, D, E, F, and H are calculated from the data shown in Table 1 and Table 2. Column G shows the calculation for the Severity Index shown in Equation 2. Column I shows the results from Equation 1. Column J shows the results from Equation 2.

Table 5: Half-mile Calculations for Sample Site

From [A]	To [B]	Crashes [C]	PDO [D]	Injuries [E]	Fatalities [F]	Severity Index [G] = D+3E+ 8F	ADT [H]	Crash Rate [I] =f(A,B,C,H)	Severity Rate [J] =f(A,B,F,H)
6.60	7.10	1	0	1	0	3	2900	0.629	1.888
6.70	7.20	2	0	2	0	6	2900	1.259	3.776
6.80	7.30	3	1	2	0	7	2900	1.888	4.406
6.90	7.40	3	1	2	0	7	2900	1.888	4.406
7.00	7.50	3	1	2	0	7	2900	1.888	4.406
7.10	7.60	9	5	4	0	17	2900	5.665	10.700
7.20	7.70	9	5	4	0	17	2900	5.665	10.700
7.30	7.80	11	5	6	0	23	2900	6.923	14.476
7.40	7.90	12	5	7	0	26	2900	7.553	16.364
7.50	8.00	12	5	7	0	26	2900	7.553	16.364
7.60	8.10	5	1	4	0	13	2900	3.147	8.182
7.70	8.20	4	1	3	0	10	2900	2.518	6.294
7.80	8.30	6	3	3	0	12	2900	3.776	7.553
7.90	8.40	5	3	2	0	9	2900	3.147	5.665
8.00	8.50	7	4	2	1	18	2900	4.406	11.329
8.10	8.60	7	4	2	1	18	2900	4.406	11.329
8.20	8.70	7	4	2	1	18	2900	4.406	11.329
8.30	8.80	2	1	0	1	9	2900	1.259	5.665
8.40	8.90	2	1	0	1	9	2900	1.259	5.665
8.50	9.00	0	0	0	0	0	2900	0.000	0.000
8.60	9.10	0	0	0	0	0	2900	0.000	0.000
8.70	9.20	1	0	1	0	3	2900	0.629	1.888
8.80	9.30	6	4	2	0	10	2900	3.776	6.294
8.90	9.40	6	4	2	0	10	2900	3.776	6.294

Once the crash rate and the severity rate were calculated, they were compared against the averages across the district (see Table 6). Crash rates that were one standard deviation above the district average are highlighted in light gray. Those greater than two standard deviations above the district average are shown in dark gray. After this analysis, the number of locations to be analyzed was narrowed further. If there were more than 6 crashes at the location and the location was either three standard deviations above the district crash rate or 2 standard deviations above the district average for both crash rate and severity rate, it was tagged as an atypical high accident location (HAL). Those segments are shown in the thicker black box. Adjoining atypical high locations were then clustered together into one possible location for deploying AITS – State Route 199 Del Norte County, Postmile 7.3-8.8.

Table 6: District Accident Rates

	Simple Crash Rate (AR)				Severity Rate (SR)		
	Average Rate	**Standard Deviation**	**avg + 2 sd**	**avg + 3 sd**	**Average Rate**	**Standard Deviation**	**avg + 2 sd**
District Average	**1.53**	2.25	**6.04**	**8.30**	**3.10**	5.27	**13.65**

The crash rate for the entire location was then calculated and was ranked against the 33 other possible locations. This location ranked 31 out of 34. If it has been one of the top 20 location, the location would be analyzed for crash trends. This information will next be used to identify potential VII solutions.

$$\begin{aligned}
\text{Crash Rate} &= \frac{12\,crashes * 1{,}000{,}000}{2{,}900\,veh/day * 0.7\,mi * 365.25\,days/year * 3\,years} \\
&= 5.39\,crashes/million\;veh-mi\;travelled \\
\text{Severity Index} &= 5\,pdo\;crashes + 3(7\,injury\;crashes) + 8(0\;fatality\;crashes) \\
&= 26 \\
\text{Severity Rate} &= \frac{26 * 1{,}000{,}000}{2{,}900\,veh/day * 0.7\,mi * 365.25\,days/year * 3\,years} \\
&= 11.69\,weighted\;crashes/million\;veh-mi\;travelled
\end{aligned}$$

3.1.2. Results

Analysis identified thirty-four locations as high accident locations. The twenty locations with the highest weighted accident rates were selected for individual analysis and to carry on to the next stage of this project as potential locations for deployment of technologies. Although each location had a simple crash rate ranking and a severity rate ranking, these values are not necessarily completely indicative of the suitability of a location for deploying VII systems. The information presented is simply one input into that choice.

Another input into the selection of deployment locations could be the overall safety of the road. The five routes with the highest simple crash rate are:

1) SR 169 in Del Norte County,
2) SR 200 in Humboldt County,
3) SR 254 in Humboldt County,
4) SR 20 in Mendocino County, and
5) SR 175 in Lake County.

When the severity of the crashes is considered, the five routes with the highest rank are:

1) SR 169 in Del Norte County,
2) SR 254 in Humboldt County,
3) SR 200 in Humboldt County,

4) US 199 in Del Norte County, and
5) SR 175 in Lake County.

For the locations that ranked in the top twenty in crash rate, a location analysis was completed. To assist in analyzing the top locations, this information was summarized by location for collision type, road condition, surface, primary collision factor, party type, object struck primary, other associated factors, and sobriety. These counts were then converted to percentage of crashes or parties at the given location with the given attribute and compared against the percentages for all crashes or parties involved in crashes across the district.

The location analysis was presented to a Caltrans District 1 advisory group consisting of engineering, planning, fleet operations, and safety staff for their evaluation, comment and recommendations. Based on the analysis and their knowledge and experience with the nominated locations, the advisory group selected two specific locations for further study and potential implementation of VII safety countermeasures. These high priority locations were on US 199 in Del Norte County in the vicinity of postmile 23 and postmile 27.

The following sections provide detailed descriptions, maps, roadclips, and aerial photos of the two identified high-priority sites, identified through the crash analysis, for which VII interventions may be applicable.

Candidate Location 1

Road Location: Del Norte 199 PM 22.60-23.60

Average Daily Traffic (ADT): 2900 veh/day

Simple Crash Rate (CR): 12.27 crashes/million vehicle-miles

Severity Rate (SR): 22.66 weighted index

# of Crashes: 39 total

25 property damage only (PDO)

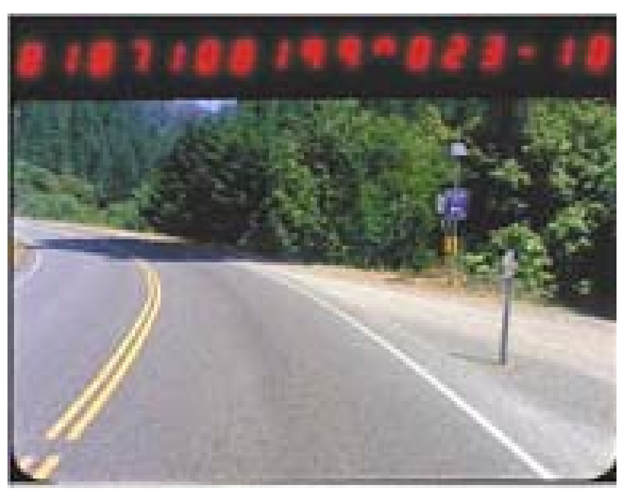
13 crashes with injuries

1 crashes with fatalities

Road Description: Undivided highway with conventional access; it has a striped median and no barriers. There is one lane in each direction. This is a curvy location in between a steep hillside and a guardrail with large vegetation. There is a turnout at PM 23.1.

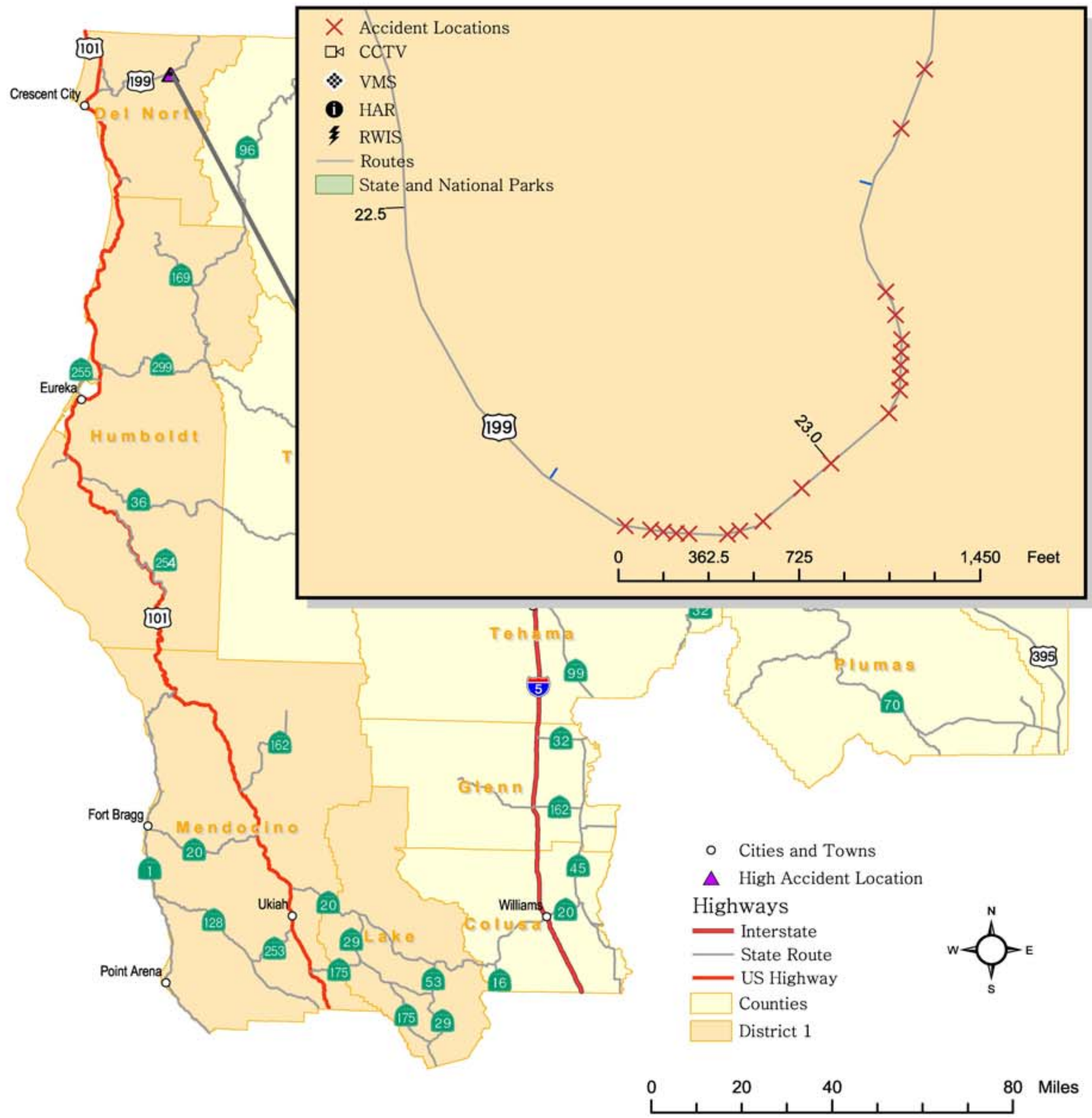
Location Totals: <u>39 total crashes</u>

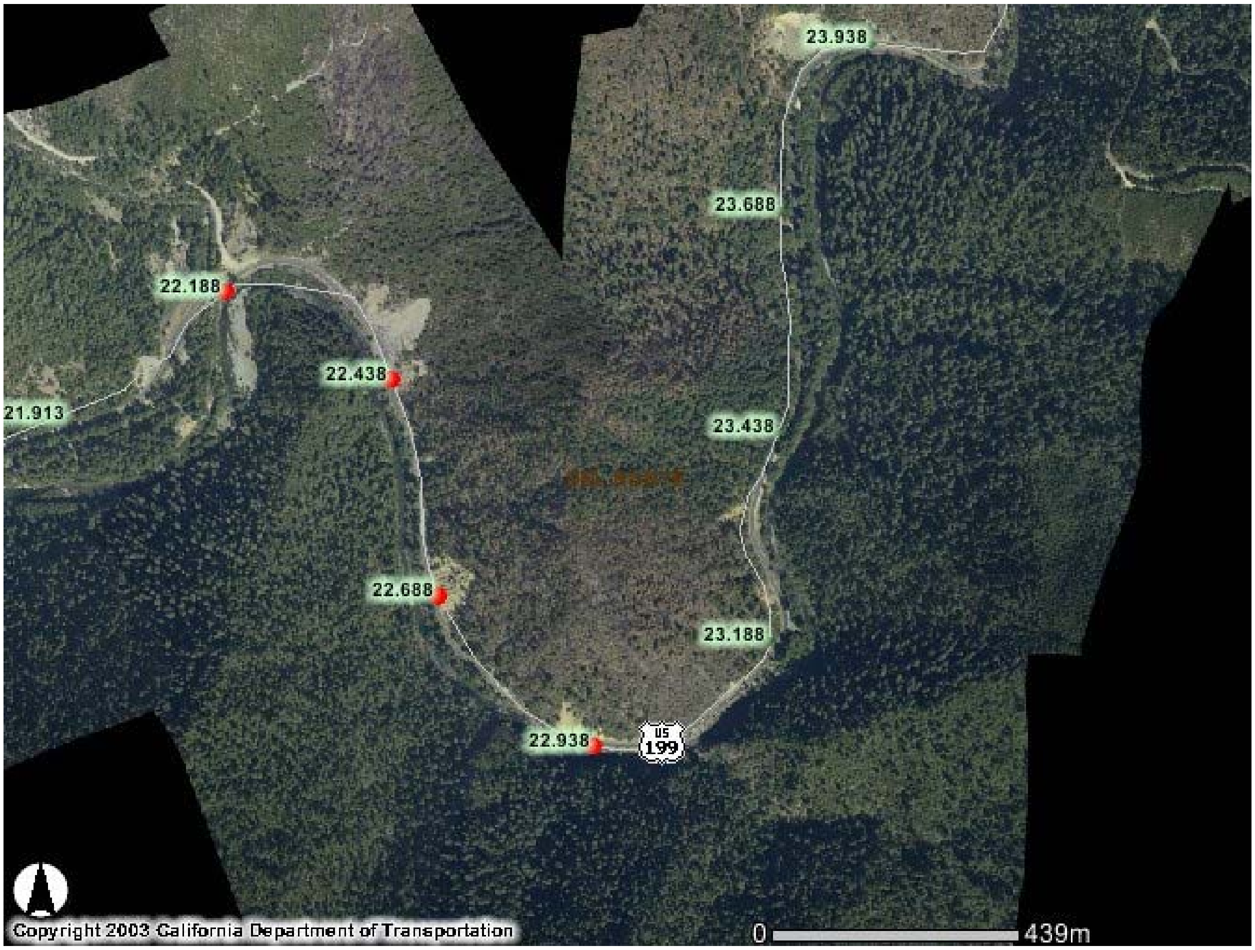
- 13(41%) were head-on or sideswipe (13% district-wide)
- 34(69%) were on wet, snowy, or icy roads (31% district-wide)
- Speeding primary factor in 19 (49%)
- Of the 65 parties involved in crashes, 16 (25%) were large vehicles (truck or school bus) (13% district-wide)



DN 199 PM 22.8 **DN 199 PM 23.1**

US Route 199
Del Norte County Postmile 22.60 - 23.60




23.938
23.688
22.188
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21.913
23.438
22.688
23.188
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US 199
Copyright 2003 California Department of Transportation
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439m

Candidate Location 2

Road Location: Del Norte 199 PM 26.60-27.80

Average Daily Traffic (ADT): 2900 veh/day

Simple Crash Rate (CR): 8.39 crashes/million vehicle-miles

Severity Rate (SR): 18.36 weighted index

# of Crashes: 32 total

18 property damage only (PDO)

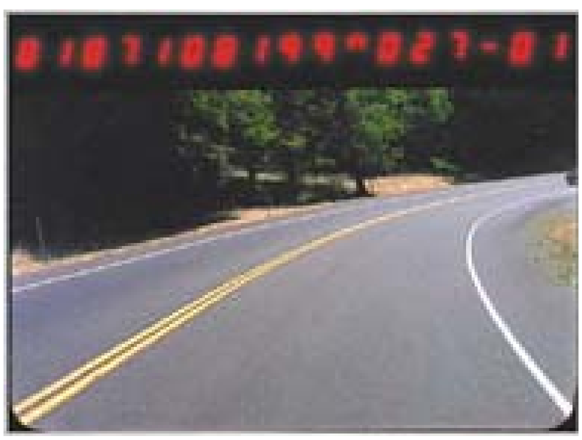
12 crashes with injuries

2 crashes with fatalities

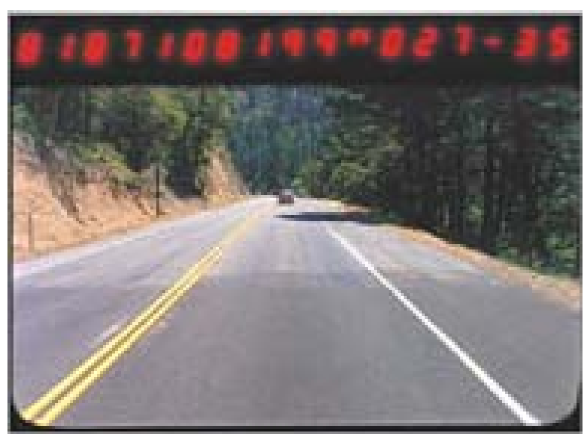
Road Description: Undivided highway with conventional access, striped medians, and no barriers. There is one lane in each direction and many sharp turns and turnouts in addition to abundant vegetation on each side of the road.

Location Totals: <u>32 total crashes</u>

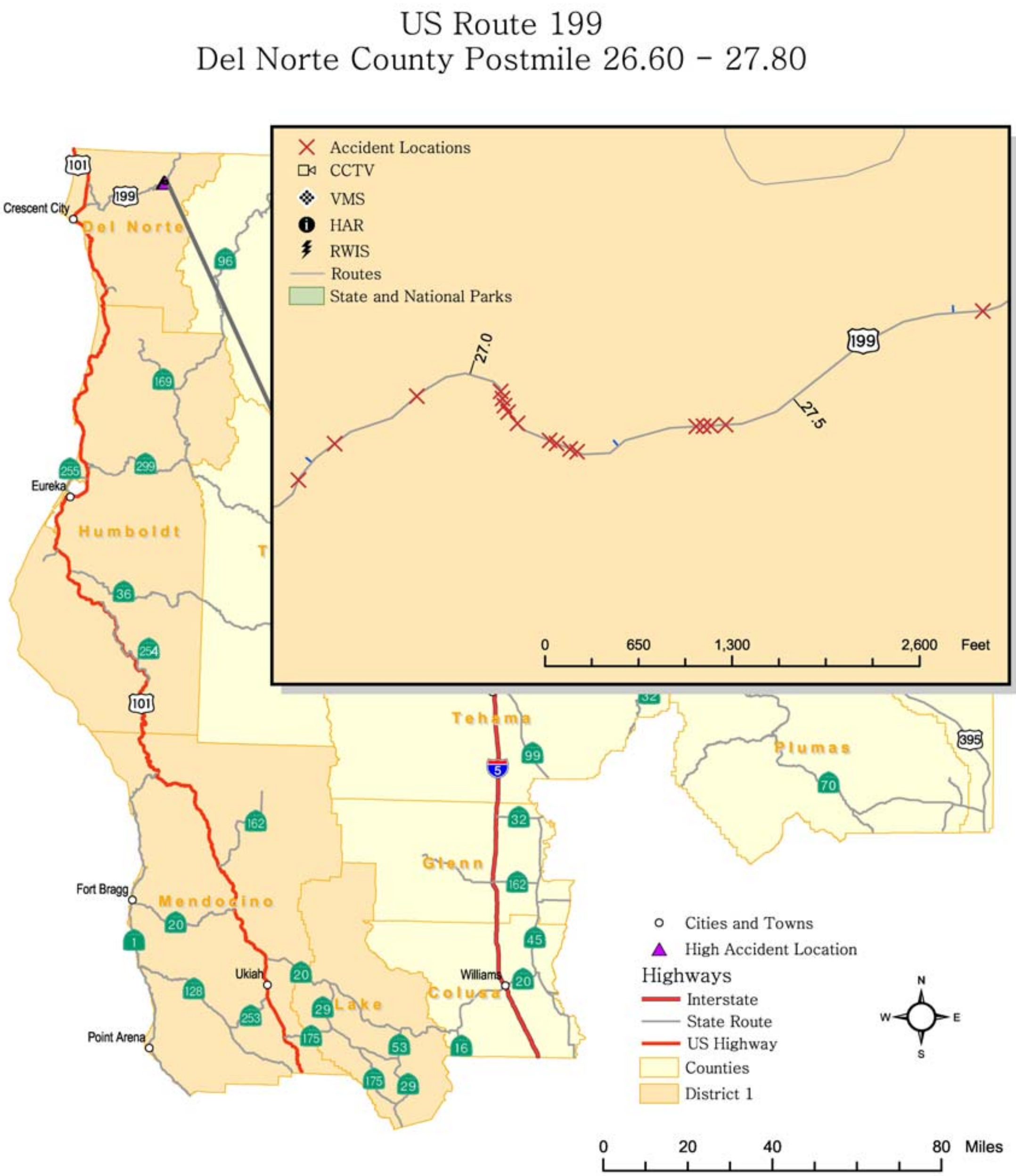
- 27 (84%) with wet conditions
- Speeding is a primary factor in 25 (78%)
- 24 of the 37 vehicles involved in crashes (65%) hit a cut slope or embankment (6% district-wide)
- Only 8/37 (22%) parties hit another vehicle (63% district-wide)



DN 199 PM 27.01



DN 199 PM 27.35


US Route 199
Del Norte County Postmile 26.60 – 27.80
Accident Locations
CCTV
VMS
HAR
RWIS
Routes
State and National Parks
27.0
27.5
199
0
650
1,300
2,600
Feet
Crescent City
Del Norte
Eureka
Humboldt
Fort Bragg
Mendocino
Ukiah
Point Arena
Lake
Williams
Colusa
Glenn
Tehama
Plumas
Cities and Towns
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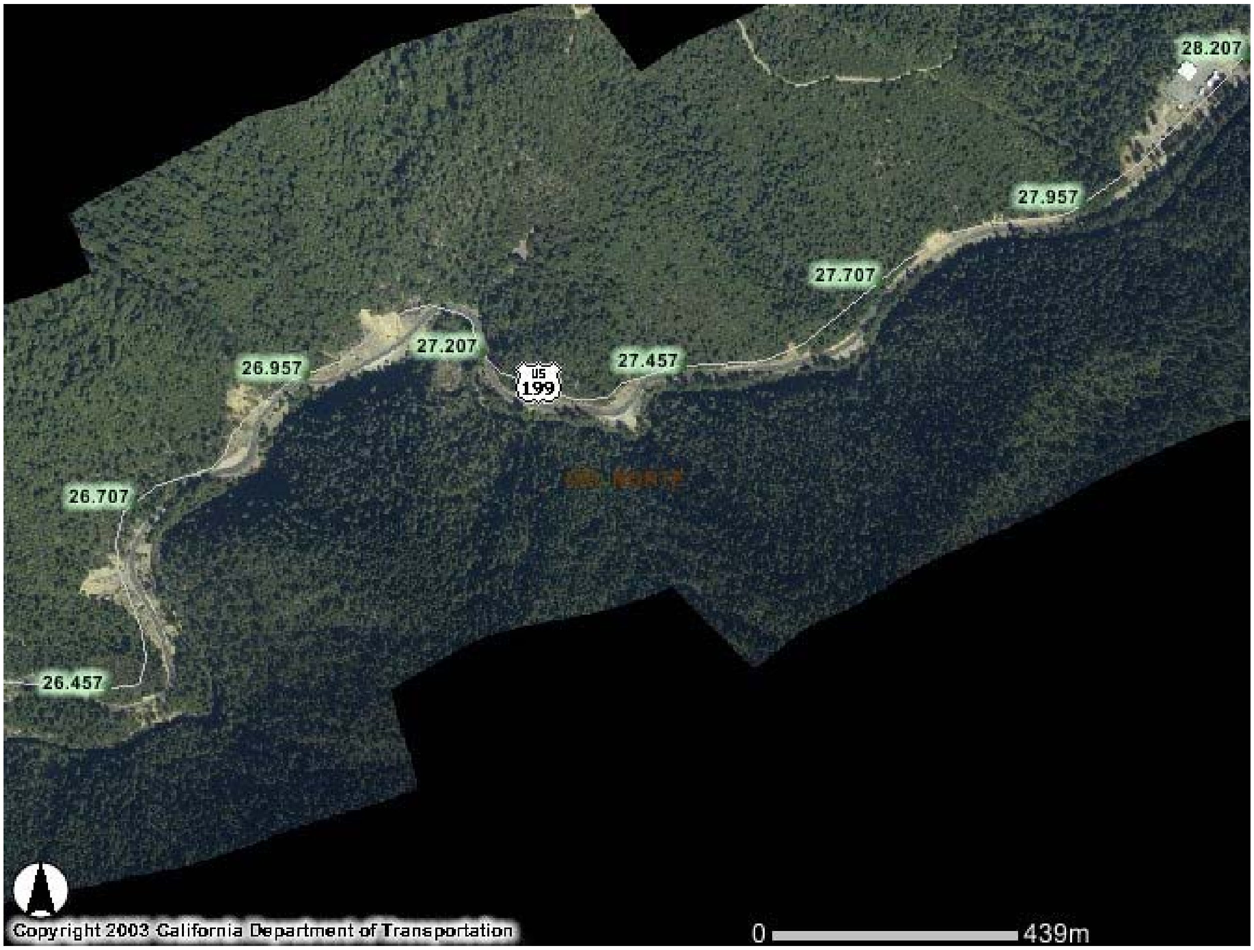
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3.2. Additional Recommendations of Caltrans Advisory Group

The interim report with the summarized crash data (Ballard, 2003) was submitted to Caltrans and reviewed by an advisory committee of District 1 safety, planning and fleet management staff. The committee was asked to review the candidate sites listed in the crash analysis and to recommend the highest priority sites.

In addition to selection of the two highest priority sites identified by the crash analysis, two additional sites that did not appear in the locations of highest crash frequency were selected for consideration. These recommendations were based on the experience of District 1 staff and their priorities for addressing identified problems. These additional sites were Mendocino County US 101 near postmile 92 (Jitney Gulch) and Humboldt County US 101 between approximately postmile 1 and postmile 6 (Richardson Grove State Park).

The Jitney Gulch site between PM 91 and PM 93 on US 101 in Mendocino County is problematic because of a significant change in highway geometry that can surprise a complacent or distracted driver. Numerous incidents and crashes have occurred in the vicinity of the narrow, curving Jitney Gulch bridge in this area. The advisory group stated that existing warning signs are insufficient to slow fleet vehicles as they approach the bridge. They commented that a warning device using auditory warnings, perhaps received on citizens band radio, could be more effective.

The Richardson Grove State Park site is on US 101 in Humboldt County between approximately postmile 1 and postmile 6. The section is problematic for several reasons. For northbound traffic, this is the first encounter of US 101 with a coastal redwood forest. Speed limits are decreased, curves become sharper and more numerous, shoulders and safety zones are narrowed by redwoods at the road's edge, and the canopy creates areas of relative darkness interspersed with bright sunlight. Drivers may be distracted by the scenery. Lane departures become more likely and more critical.

Candidate Location 3

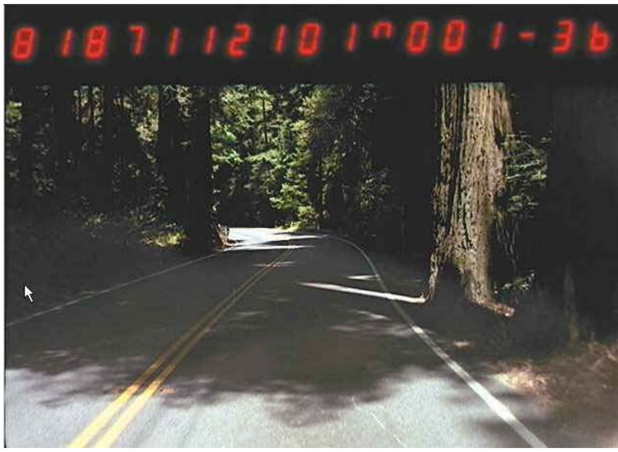
Road location:	Mendocino 101 PM 92 - 94
Road description:	US 101 transitions between paved four-lane and paved two-lane with seven relatively sharp curves and one narrow bridge between PM 92.7 and PM 93.7. Jitney Gulch Bridge at PM 93.
Challenges:	Speed habituation of drivers approaching this area that requires significantly reduced speeds and more precise vehicle control to avoid run-off-road accidents in the curves and on the bridge approaches. Existing signing appears inadequate for ensuring effective traffic control.

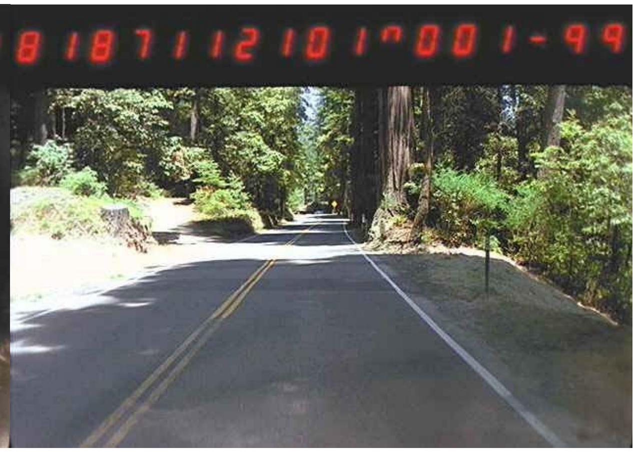
Candidate Location 4

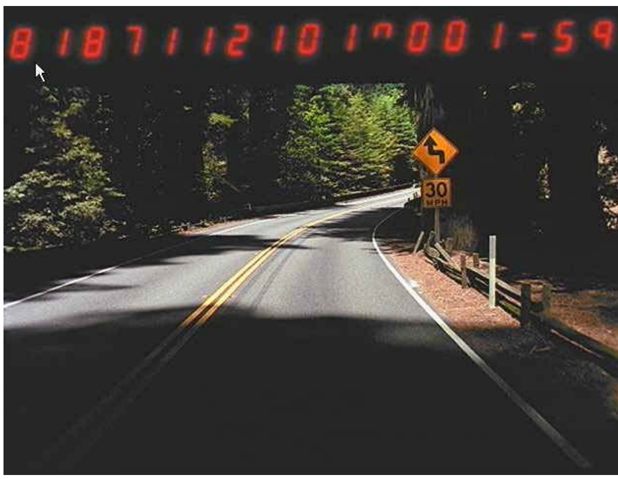
Road location: Humboldt 101 PM 1 - 5

Road description: Undivided highway with conventional access, striped medians, and no barriers. There is one lane in each direction and many sharp turns and turnouts in addition to abundant vegetation on each side of the road.

Challenges: In this State Park, US 101 provides a driving challenge as it passes through a large stand of coastal redwoods. Roadway alignments and geometry are constrained by the forest. Speed limits are decreased, curves are sharp and numerous, shoulders and safety zones are narrowed by redwoods at the road's edge, and the canopy creates areas of relative darkness interspersed with bright sunlight making vision difficult. Drivers may be distracted by the scenery. Lane departures become more likely and more critical.



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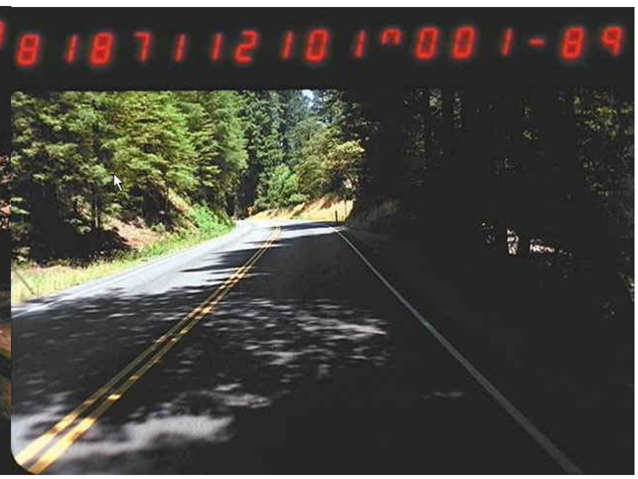
MPH



4. Applicable Vehicle-Infrastructure Integration Systems

Vehicle-Infrastructure Integration Systems combine sensor, communication, display and control technologies to provide real-time information transfer between the vehicle and the roadway infrastructure. Sensors may be infrastructure-based or vehicle-based. Information may be provided to drivers to support their decision-making and vehicle control or to partially automated systems to support automated control. Examples of VII functions include safety, traffic flow enhancement, and navigation.

Safety VII systems encompass the following areas:

Crash avoidance. Warning of immediate hazards undetectable by the vehicle (blind curves, vehicles in crossing path, signalized intersections, etc.)

- crash avoidance -- provision of environmental and/or roadway condition information to inform vehicle speed adjustments
- crash avoidance -- provision of roadway geometry information to inform vehicle speed adjustments
- crash avoidance -- urgent message provided when vehicle is not slowing appropriately for a red traffic signal or stop sign
- collision avoidance -- detection of animal activity near the road and provision of warnings to drivers/vehicles
- enhanced driver awareness -- warning of obstacles the driver may not be aware of (such as a pedestrian warning when making a turn in a complex urban intersection)
- enhanced driver awareness – warning of impending departure from the traffic lane when the driver is sleepy, complacent or distracted
- safety compliance -- provision of speed limit information appropriate to current conditions and/or policies

VII applications for traffic flow include:

- Micro-dynamic speed control -- providing precise control of speed to individual vehicles in a traffic stream, in order to smooth traffic and optimize flow
- Traffic signal response assist -- providing driver assist in start-up on the green signal

To support navigation, vehicles can collect mapping data to refine digital map databases and provide these corrections in real time to a central database manager. Updates can also be delivered to vehicles.

4.1 Downstream Hazard Warnings

Hazard warnings can be transmitted to the vehicle via numerous channels including radio and microwave.

Citizens Band (CB) radios are monitored by a majority of fleet drivers in order to exchange information on traffic, road conditions, and other factors that could influence their trips. An automated system using this communication band could be used to communicate hazard information to a large percentage of fleet drivers. A much smaller percentage of automobile drivers monitor CB transmissions. Alerts provided by such a system would not reach most automobiles.

One such system is the Wizard CB Alert System developed by TRAFCON Industries in coordination with PennDOT to enhance the safety of work zones. This device automatically broadcasts prerecorded messages on any selected channel, usually on CB Channel 19. The messages are typically about 10 seconds in length and are repeated every 30, 60, or 90 seconds. The system automatically monitors communication activity and broadcasts only when the channel is clear in order to avoid interfering with communications. The effective range of the transmitter is approximately 4 miles. Drivers must have a CB radio and have it tuned to the appropriate channel in order to receive the warning message. The Wizard CB consists of the Alert and Information Radio, a standard CB antenna, and a 12-volt power source.

The Wizard CB Alert System has been successfully tested in numerous field evaluations. A detailed study in Iowa examined the response of truck drivers to a Wizard CB alert of a roadway painting operation on rural I-35. Approximately 75% of truckers had a CB radio tuned to channel 19 when they passed through the work area. Of the drivers who heard the warning before they passed through the work area, 89% stated that the Wizard CB provided an effective warning. Only one driver felt that the system was obtrusive or annoying and the drivers unanimously agreed that use of the system should be maintained or expanded. In Missouri, an evaluation found a decrease in traffic speeds with no change in speed variance. Larger numbers of vehicles moved into the open lanes at greater distances from the work zone. There were no technical difficulties with the alert radio system. In a Kansas evaluation, there were no significant effects of the alerting system on traffic flow or safety. It was noted in the Kansas evaluation, though, that drivers had a longer sight distance and could see the work zone from longer distances. In addition, the highway geometry, terrain and traffic was less challenging. It could be concluded from these evaluations that the Wizard CB Alert System provides a useful initial or additional warning for work zones, slow moving operations, or fixed hazards in areas where fleet operators cannot see a hazard in time to safely respond.

4.2. Lateral Position Warnings

The lateral position and motion of a vehicle within a lane can be sensed by numerous technologies including GPS, image processing, laser, or electromagnetic sensors. When an imminent or actual lane departure is sensed, a signal is sent to the driver in the form of an audible warning noise or a vibration in the vehicle seat. This virtual rumble strip technology can make many of the benefits of a rumble strip available on any roadway with painted lane delineation.

Numerous manufacturers are developing or marketing lateral position warning systems for American, European, and Asian vehicles. In addition, there is considerable research and development related to image processing algorithms, predictor equations, and driver interfaces.

Visteon Corp. is developing a radar-based road departure crash warning technology. The system warns drivers if they are drifting toward the edge of their lanes or if they are approaching a curve at too fast a speed for the roadway geometry. Based on a system developed by AssistWare, Inc., this system is in the prototype stage, has been tested in limited numbers in Mack and other trucks, and is not yet available on the market.

Iteris, Inc., a division of Odetics, Inc., has recently introduced an aftermarket version of its Lane Departure Warning System™ that may be retrofitted to existing fleet vehicles. Originally developed for use on commercial trucks, the system has been in use in Europe since 2000 on Mercedes Actros trucks. Several automobile manufacturers are making a variant of the technology available in passenger cars. More recently, it has been made available on fleet purchases in the United States. One major California hauler of hazardous materials has purchased a fleet of trucks featuring this technology. A version of the system can be purchased for retrofit on many American-made fleet vehicles.

As described by the manufacturer:

> The AutoVue Lane Departure Warning System uses a windshield-mounted camera that tracks the lane markings and "virtually" provides the functionality of rumble strips anywhere there are lane markings. Using image recognition software and proprietary algorithms, the system monitors the relative position of the truck and when it unintentionally crosses the lane markings, the unit automatically emits a distinctive rumble strip sound on the right or left side depending on the direction of travel, alerting the driver to make a correction. Use of the truck's turn signals automatically overrides the system, which helps promote the use of turn signals.
>
> Iteris has developed retrofit kits for Class 8 trucks that will enable virtually any fleet or owner/operator to easily outfit their trucks with the LDW system. The LDW aftermarket system is available through the OEM modification centers or can be purchased directly from Iteris. It comes with a complete installation kit which consists of a wiring harness, speakers, switch, connectors and pre-made cables. The LDW kit can be purchased and installed for approximately $1,000 on any Class 8 truck with a J-1939 data bus which includes most trucks built since 1999.

5. Conclusions

The transportation corridor connecting northern California with central Oregon provides significant challenges to the transportation engineer and the traveling public. The terrain is mountainous, a large percentage of the roadways are narrow, rural two-lanes with short radius turns and narrow shoulders against embankments, guardrails, and vegetation. Even the major roadways such as US 101, which alternates between divided four-lane and narrow, winding two-lane can provide challenging conditions for travelers.

Weather and geography are the sources of many of the transportation challenges. Travelers throughout the corridor must contend with diverse and rapidly changing weather conditions including snow, high winds, fog and heavy rain. The combination of varied driving conditions and abundant off-road, commercial and recreational traffic produces an immediate and expanding need for increased traffic safety measures and information dissemination techniques.

On many of the roadways, traffic is characterized by a mix of automobiles, busses, and large trucks. An unusually high percentage of the large trucks are hauling logs and lumber in support of a major industry in these counties. In some areas, the narrow, curving roads provide a major challenge to the large trucks.

Analysis of crash data using Geographic Information System (GIS) techniques and Caltrans data is a fruitful means of identifying problem sites. Clusters of crashes with similar characteristics at a common location suggest a need for additional safety measures. By using the Caltrans Road Clip files associated with the location, it is possible to develop a good idea of the nature of the problems. Transportation engineers who are familiar with the areas can validate and prioritize the recommended solutions.

One class of solutions that has not yet achieved wide application in the rural environment is that of vehicle-infrastructure integration (VII) systems. VII supports the drivers' perceptual, cognitive, and driving response behavior through the application of sensors, communication devices, information displays, and vehicle control devices. Sensors may be contained in the vehicle (in the form of laser, radio-frequency, magnetic, image processing, GPS, radar, or other technology) or in the infrastructure. Communications may be between vehicle-infrastructure, infrastructure-vehicle, or vehicle-vehicle. The objective may be to provide the driver with more information about the infrastructure, provide the infrastructure with more information about the vehicle, or provide the driver of one vehicle with more information about another vehicle's location, path, intentions, or driving conditions. While some VII systems may assume control of a vehicle during hazardous driving conditions, these were out of the scope of the current effort. This study was limited to systems that provide information or warnings to the driver.

While most VII solutions have been developed for urban transportation engineering problems, many may be as applicable for rural safety problems. Such interventions may find a fruitful application in rural areas. In many ways, driving in rural areas can be more challenging than driving in urban areas. Rural speeds are higher; roadways may be narrower; roadways may be unpaved; roads may have steeper grades and shorter radius curves to meet terrain requirements. Trips are longer making driver fatigue and inattention a more significant issue.

The most common kinds of crashes in rural areas are run-off-road situations resulting from a drowsy, complacent, or distracted driver. Systems are available or under development that can alert the driver and even take control of the vehicle when such a crash is predicted. A substantial reduction in crashes could be achieved by providing drivers with an alert when a lane excursion is predicted by the on-board computer systems.

In rural areas, drivers are likely to encounter unexpected obstacles and driving conditions. Unexpected weather and associated road conditions are a serious challenge. Drivers need to be alerted to temporary obstacles in the roadway or blockages due to work zones, mud slides, animals, traffic incidents, vehicle width or height limitations, or similar problems. VII technologies provide approaches for meeting these needs in the rural environment.

Specific challenges were identified at four sites in Caltrans District 1 in coastal Northern California. VII systems were identified that could be used to address those specific problems. The following chapter provides WTI's recommendation for technology that could be deployed to address the challenges.

6. Recommendations

The goal of this effort was to identify a small number of highway locations in Caltrans District 1 at which significant safety-related problems could be identified and addressed with VII solutions. Specific VII technologies that might be used to address those problems were to be identified and recommended. This section details those findings and recommendations.

The identified high priority locations are essentially three areas. Because of their proximity, similar terrain, and the high percentage of fleet traffic that crosses both sites, we have combined DN 199 PM 23 and DN 199 PM 27 into one recommendation. ME 101 PM 92 provides very different safety challenges and requires different solutions. HU 101 PM 1–5 provides challenges somewhat similar to the Del Norte County locations but is geographically distant from them.

6.1 Mendocino 101

The primary challenge at the Mendocino County site is that large trucks transitioning from the surrounding four-lane highway onto this short length of two-lane highway do not decelerate quickly enough and enter the two-lane at an excessive speed. This has resulted in frequent crashes, run-off-road incidents, and spilled loads in the vicinity of the Jitney Gulch Bridge at PM 93. The Caltrans advisory committee recommended that WTI explore a means of providing audible warnings, possibly on a citizen's band radio system, of the hazards at this location in an attempt to reduce truck speeds. Based on earlier evaluations, it is estimated that these alerts on channel 19 would be received by a majority of truck drivers passing through the site.

WTI recommends installation of a Wizard CB Alert System in this area to provide warning information to supplement the existing standard signage. The Wizard CB would be programmed to automatically transmit a brief message on CB channel 19 every 60 seconds warning of the fixed hazards including the narrowed roadway, curves, and bridge.

The objectives of this deployment would be to achieve reductions in mean speed, speed variance, and crash frequency on this short length of two-lane on US 101 approaching and in the vicinity of the Jitney Gulch Bridge.

6.2 Del Norte 199

The primary challenge at the combined Del Norte 199 site (PM 23 and PM 27) is lane departures due to narrow roads with short radius turns, a frequent lack of shoulders, and inclement weather conditions. Lane departure crashes involve both head-on/sideswipe collisions resulting from centerline excursions and run-off-road collisions with embankments, obstacles, and guardrails. A significant portion of the traffic is large vehicles (trucks and busses).

WTI recommends that a formal field deployment and evaluation of the Iteris Lane Departure Warning System™ be conducted with the participation of one or more fleet operators operating in this area. The LDWS predicts lane departures using image processing technology that tracks the standard lane delineation markings. The system alerts the driver to current or potential lane *excursions using auditory warnings or a seat vibrator. The LDWS would be retrofitted to a group of 10 – 20 compatible fleet vehicles. Cost of installation is estimated at $1000 per vehicle.*

The objective of this deployment would be to reduce the variance in lateral lane position by the participating fleet vehicles. This would, in turn, reduce the frequency of lane excursions.

6.3 Humboldt 101

The primary challenge at the Humboldt site is lane departures due to narrow, curving roads with a frequent lack of shoulders and inclement weather conditions. The canopy of trees over the roadway creates alternating areas of light and darkness making visual tracking of the roadway more difficult. Lane departure crashes involve both head-on/sideswipe collisions resulting from centerline excursions and run-off-road collisions with embankments, obstacles, and guardrails.

WTI recommends that a formal field deployment and evaluation of the Iteris Lane Departure Warning System™ be conducted with the participation of one or more fleet operators operating in this area. The LDWS predicts lane departures using image processing technology that tracks the standard lane delineation markings. The system alerts the driver to current or potential lane excursions using auditory warnings or a seat vibrator. The LDWS would be retrofitted to a group of 10 – 20 compatible fleet vehicles.

The objective of this deployment would be to reduce the variance in lateral lane position by the participating fleet vehicles. This would, in turn, reduce the frequency of lane excursions.

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