An evaluation of the dynamic curve warning system in the Sacramento River Canyon
by Lani Alyson Tribbett

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
Montana State University

Abstract:
The dynamic curve warning system in the Sacramento River Canyon consists of five dynamic curve warning signs at five different curves. The system has been installed to inform and prepare the drivers of upcoming potentially hazardous curves. The five sites are located on Interstate 5, in Shasta County, California. This report includes the results of the evaluation conducted on the effectiveness of the system.

The individual sign systems include a radar unit to measure speeds of approaching vehicles and a changeable message sign to display the corresponding speeds to the travelers. Four site visits were made to collect data both before and after the installation of the system: one before the installation, and the remaining three at different times after the installation date. Measures of effectiveness included crashes, vehicle speeds, driver behavior (erratic maneuvers), motorist opinion, and maintenance personnel opinion. Statistical analyses were conducted on the speed and erratic maneuver data to show if the observed changes were statistically significant.

Because crash data could only be obtained for the six-month period following the installation date, a thorough crash analysis could not be completed. A brief analysis was done showing slight reductions at two of the five sites, while the other three experienced slight increases. Truck speeds were found to significantly decrease at three of the five sites, while non-truck speeds were found to significantly decrease at two of the five sites. Two of the five sites experienced significant reductions in the percentage of drivers conducting erratic maneuvers. Overall, drivers favored the dynamic curve warning system. Maintenance personnel reported a couple of problems that had either been solved or were being modified at the time this report was written.

Results show the dynamic curve warning system to be most effective at lowering speeds at the curves with the more severe horizontal and vertical curves. Due to the uncertainty of interpretation of the erratic maneuver data, the results of the final evaluation were not influenced by erratic maneuvers. Drivers and maintenance personnel were generally supportive of the system. For a more accurate evaluation, further crash analysis should be conducted after more crash data can be obtained.

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MONTANA STATE UNIVERSITY – BOZEMAN
Bozeman, Montana

April 2000

APPROVAL

of a thesis submitted by

Lani Alyson Tribbett

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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Date April 11, 2000

ACKNOWLEDGMENTS

I would like to thank my wonderful committee members: Jodi Carson, John Mounce, and Patrick McGowen. A special thanks to Pat for his help and guidance during the course of this study. We have put a lot of time into this project, and I appreciate all you've done. Jodi, you've been a great advisor and mentor to me the past couple years, and I thank you for all of your help and your eagerness to host our Christmas parties. Thanks also to Nancy Mounce, who has done an excellent job helping me to perfect this report.

Most importantly, I want to express my immense gratitude to all of my patient family members and friends. They have been there to support me through some hectic crunch times and have tolerated my occasional spells of grouchiness, and I appreciate all of you.

This research was supported by the Western Transportation Institute and the California Department of Transportation (Caltrans). I would like to thank all of the students at the Western Transportation Institute and the employees at Caltrans that have helped me to complete this study. My education at Montana State University has been a wonderful experience, and I appreciate the opportunities and assistance I have been given in order to complete it and succeed.

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ABSTRACT

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CHAPTER 1

INTRODUCTION

In 1994, there were approximately 6.5 million motor vehicle crashes in this country, which cost the United States over $150 billion in associated medical and legal expenses, insurance administration costs, lost productivity, and property damage (1). It is generally acknowledged that countermeasures must be developed and implemented by states to reduce the frequency and severity of vehicle crashes. One method of improving conditions at high crash locations involves alerting motorists of approaching hazards or conditions through the use of traffic control devices, including signs, signals, and pavement markings. Different types of signs can be installed, depending on the specific needs of the particular area. General sign types include regulatory, warning, guidance, recreational, and construction or maintenance. Specifically, warning signs are used to inform motorists of hazards to minimize crashes and reduce injuries and crash-related costs. Warning signs are commonly installed as permanent safety improvements, and can be accompanied by regulatory signs.

Because of cost considerations and geographic constraints, such as mountains, canyons, and waterways, some sections of highways are constructed below the design speed. Specifically, some horizontal curves may need to have a radius shorter than can be traversed safely at the operating speed for the rest of the highway. Additionally, heavy trucks may need to travel at lower speeds on long, steep downgrades in order to avoid a runaway situation. Where geometric features, such as curves of short radii and long and steep downgrades, cannot feasibly be eliminated from a highway, appropriate warning signs should be placed in advance of these features to warn the driver of a reduction in appropriate speed.

Types of warning signs vary both in function and effectiveness. Static warning signs are usually installed at locations where an advisory speed differs from the design speed of the proceeding section of the roadway. Unfortunately, drivers can become desensitized to some such common applications. In an attempt to increase effectiveness by catching the attention of motorists, changes can be made to the traditional hardware and placement. For example, to attract drivers and possibly increase their attentiveness, flashing beacons can be added to static signs, or warning signs can be mounted over travel lanes.

Intelligent Transportation System (ITS) advancements provide a number of new possibilities for warning motorists of approaching hazards. For instance, ITS technologies, such as changeable message signs (CMS), have proven to be effective in informing and warning drivers, resulting in reductions in crashes and related costs (2). These signs are used by Departments of Transportation to display dynamic information to drivers. CMS are still relatively new and have had limited use in rural areas. Some CMS can present only one of a few predetermined messages, while others can display any message at any time. CMS are useful in problem areas, such as areas with recurring congestion, adverse weather conditions, and frequent road closures or crashes.

Background

There are strong correlations between the speed of a vehicle and the probability of the vehicle being involved in a crash. Moreover, speed is also related to the severity of a crash. In 1997, 30% of all fatal crashes in the United States had speed reported as a contributing factor. Crashes in which speed was found to be a contributing factor accounted for 13,000 deaths and 41,000 critical injuries. These figures represent the investigating officer's interpretation of "speeding" or traveling at a "speed too fast for conditions" as *one* of the contributing factors to the crash and should be interpreted with caution (3). However, the numbers clearly suggest that excessive speed is a major safety challenge.

Many traditional solutions exist to mitigate speed-related crashes, such as (1) adjusting the speed limit and increasing enforcement; (2) installing static warning signs in advance of changes in alignment, access, or road surface where high speeds could increase the likelihood of a crash; and (3) reconstructing alignments, cross-sections and clear zones to improve a driver's chances to recover from overdriving the highway (4). These solutions may not always be feasible and speed-related crashes may still exist regardless of the countermeasures put into effect.

There are many types of rural ITS applications that can complement the existing infrastructure to improve the safety and efficiency of the transportation system. Some rural ITS applications can provide information to the driver regarding unsafe traveling speeds, particularly in relation to an upcoming hill or curve. The primary purpose of these ITS applications is to reduce crashes by better informing the drivers of what lies ahead on their route and posting an appropriate advisory travel speed.

Static Signing

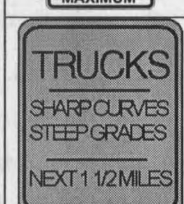
The Manual on Uniform Traffic Control Devices (MUTCD) was created in 1935 in order to regulate the use of traffic control devices with warrants. According to the MUTCD, these warrants are necessary to: "help insure highway safety by providing for the orderly and predictable movement of all traffic, motorized and non-motorized, throughout the national highway transportation system, and to provide such guidance and warnings as are needed to insure the safe and uniformed operation of individual elements of the traffic stream." (5).

Warning signs must meet requirements in the MUTCD concerning application, design, and placement. To ensure that static signs will "(1) fulfill a need; (2) command attention; (3) convey a clear, simple meaning; (4) command respect of road users; and (5) give adequate time for proper response" they should comply with the MUTCD and the Caltrans Traffic Manual for California (5). It is important that signs are only placed where needed to maximize their effectiveness. Unnecessary signs could result in motorists eventually learning to ignore all signs, even the imperative ones.

Static curve warning signs are used when drivers must be notified of a curve where the advisory speed has been lowered in order for drivers to safely complete it. Such static signs can be accompanied by a speed advisory plate to further increase safety conditions. Although currently under revision, the MUTCD only recognizes dynamic curve warning signs, such as CMS, but does not define specific requirements except to state that CMS should meet other warrants concerning design and application (5).

The MUTCD has a designated code for each sign, while the California Department of Transportation (Caltrans) uses a separate set of codes for identifying standard signs. Table 1 shows the different curve warning and speed signs present in the study area, their respective MUTCD symbol, the corresponding Caltrans symbol, a description of the sign, and its standard dimensions. Caltrans also has four signs not included in the MUTCD, as shown in Table 1.

Table 1. Existing Warning Sign Types (5, 6)

Graphic	MUTCD	Caltrans	Description	Standard Dimensions
	W1-2R	W5 (RT)	Right Curve	30" X 30"
	W13-1	W6 (speed)	Speed Advisory Plate	18" X 18" 24" X 24"
	No MUTCD	W4 (RT)	Curve w/ Advisory Speed	72" X 72"
	W1-4R	W1 (RT)	Reverse Curve	30" X 30"
	W1-8	W81	Chevron Alignment	18" X 24"
	No MUTCD	W4 (RT)	Curve w/ Advisory Speed	96" X 96"
	No MUTCD	R48-1	Speed Limit Plate	
	R2-4	R6(65)	Speed Limit	24" X 30"
	No MUTCD	R6-1	Speed Limit	24" X 30"
	No MUTCD	No Caltrans Symbol	Trucks: Sharp Curves; Steep Grades	96" X 96"

ITS Applications of Dynamic Warning Systems

Intelligent Transportation Systems (ITS) are the advanced technologies and management strategies used to enhance the safety and efficiency of current transportation systems. There are many different applications of ITS, including lateral collision warning devices, automated highway systems, and dynamic speed warning systems, to name a few.

Dynamic speed warning systems can be used to mitigate speed in areas where geometric features may keep drivers from safely maintaining a uniform speed. These warning signs, which may be accompanied by other signs or advisories, can be installed in advance of locations with steep downgrades, areas with weather conditions that can affect safety, construction work zones, and specific curves with high frequencies of crashes. Other states, such as Colorado, Oregon, and Washington, and some European countries have conducted studies and installed similar changeable message sign systems for speed warning and regulation. It should be noted that this area of study is relatively new in the transportation industry and few systems exist that are similar to the dynamic curve warning system installed in the Sacramento River Canyon. The dynamic curve warning system differs from the aforementioned systems because it is the first ITS application to use radar for speed measurement and to sign for a specific curve(s).

In the summer of 1998, a Downhill Truck Speed Warning System was installed in Colorado for commercial vehicles on Interstate 70. The system determines the weight and configuration of commercial vehicles weighing over 40,000 pounds as they pass a weigh-in-motion device. A CMS displays a safe speed for the drivers to travel down the steep grade. According to the evaluation conducted at the University of Colorado at Denver, the Dynamic Truck Speed Warning System has significantly reduced commercial truck speeds through the steep descent from average speeds of 41 mph to 34 mph (7).

The Oregon Department of Transportation has installed a Downhill Warning System for commercial vehicles traveling on I-84 between Pendleton and La Grande, Oregon. This system utilizes existing infrastructure, including a Mainline Preclearance System used for weigh-in-motion purposes and a CMS, both located at the top of Emigrant Hill. The Downhill Warning System integrated these two existing elements to give a warning to trucks, based on the weight and configuration of each truck. When a vehicle is identified and weighed by the preclearance system, messages are posted on the CMS. The first line reads "TRUCK ADVISORY" and the second line reads "CAUTION". The third line reads "XX MPH DOWNHILL" if an accurate weight is obtained for the vehicle. The displayed advisory speed is dependent on the measured weight of the vehicle. If an accurate weight is not obtained by the preclearance system, the third line will read "STEEP DOWNGRADE". The shipping companies utilizing this system can choose to subscribe to the Green Light Mainline Preclearance Program, which would provide personalized messages to the drivers. When a driver from a subscribing company passes through the system area, the second line displays the company name of the specific truck. An evaluation is currently underway, but no results were available for inclusion in this document. A final evaluation report should be completed in July 2000 (8).

The Washington Department of Transportation installed 13 variable speed limit signs along a 40-mile segment of Interstate 90 over Snoqualmie Pass in December 1997. Harsh weather conditions during the winter season can increase the risk of traveling this route through the Cascade Mountains. This ITS system includes loop detectors in three different locations throughout the section and the real-time traffic flows collected will help to determine safe speed limits. The CMS display safe, enforceable speed limits for current weather conditions and display messages to inform drivers of closures or the need for chains. Although the variable speed limit is enforceable, if weather conditions are severe enough to alter the speed limit, the Washington State Patrol agree they will most likely not stop anyone on the side of the roadway. A pre-installation evaluation was completed at the University of Washington through the use of simulation to determine if the traveler information conveyed externally (via the variable speed limit signs) and/or any information received in-vehicle were affecting driver behavior. This study concluded the variable speed limit signs had no statistically significant effect on a vehicle's mean speed over longer segments of the route. It was found, however, there was a statistically significant reduction in vehicle mean speed in sections immediately following a variable speed limit sign. A post-installation evaluation is in the process of being conducted and a December 2000 completion is planned (9).

Several European communities have installed changeable message signs to display variable speed limits. Loop detectors have been positioned to maintain real-time traffic flows in order to measure if the traffic is slowing downstream of the CMS. Automated enforcement is used in many areas to ensure that vehicles are following the set limits. This automated procedure eliminates the confusion that standard enforcement officers might face with a constantly changing speed limit. Although these CMS display dynamic speed information, the main purpose of the application is to maintain an adequate level of service on congested freeways; improving safety is a secondary objective (10).

Europeans also have experimented with in-vehicle speed advisories and speed limiters. With such a system, a roadside beacon is placed at dangerous areas where lower speeds are desired. When an equipped vehicle passes the beacon, a warning is given to the driver and, if appropriate, the vehicle speed is reduced. Initial trials included small test fleets that did not yield sufficient data to statistically verify any safety benefits. Larger trials are currently underway (10).

Speed warning signs also are used in construction or maintenance work zones to display speeds to both motorists and workers. These signs can be attached to a trailer and displayed to inform drivers of their current traveling speeds. The intent is to slow the drivers to reduce the number of vehicle-pedestrian collisions. Although these systems are widely used around the United States, evaluations are currently unavailable.

Report Purpose and Contents

The dynamic curve warning system installed in the Sacramento River Canyon is an example of a rural ITS application used to enhance safety. The system utilizes changeable message signs (CMS) to display dynamic warnings in advance of sharp horizontal curves and steep downgrades. It is envisioned that this or similar ITS applications can provide other roadside messaging services associated with maintenance, construction, weather, and roadway conditions. Specifically, this report: (1) describes the various evaluation sites and the dynamic speed warning system implemented (Chapter 2); (2) details the evaluation methodology (Chapter 3); (3) documents data analysis results for vehicle crashes, speed measurements, and erratic maneuvers (Chapter 4); (4) summarizes motorist and maintenance personnel opinions (Chapter 5); and (5) provides conclusions and recommendations (Chapter 6).

Interstate 5 between Redding and Dunsmuir, the area known as the Sacramento River Canyon, was selected as the demonstration site for the dynamic curve warning system because of its high traffic volumes, mountainous terrain and the number of crashes specifically related to heavy trucks. In addition to safety costs, crashes involving heavy trucks in this corridor can close the Interstate to travel for several hours. Specific curves were selected for the dynamic curve warning system based on a potential cost-benefit procedure used by Caltrans. The procedure is based on a potential estimation of crash reduction for a five-year period. Table 2 lists the data used for the cost-benefit procedure. Crashes shown in Table 2 occurred between September 1, 1992 and August 31, 1997, and are separated into fatal, injury, and property damage only (PDO) categories.

Table 2. Total Crashes for Proposed Sites (11)

Site	Total	Fatal		Injury		PDO	
		#	%	#	%	#	%
Sidehill Viaduct (PM 29.0-29.88 SB only)	30	1	3.3	13	43.3	16	53.3
O'Brien (PM 31.95-32.17 SB only)	21	0	0	6	28.6	15	71.4
Salt Creek (PM 36.7-37.3 SB only)	13	0	0	3	23.1	10	76.9
LaMoine (PM 48.8-49.1 SB only)	14	0	0	4	28.6	10	71.4
Sims Road (PM 58.1-58.2 NB only)	9	0	0	5	55.6	4	44.4

CHAPTER 2

SITE AND SYSTEM DESCRIPTIONS

Five study sites were selected by Caltrans staff, based on a quasi cost-benefit analysis. Each site has unique characteristics that must be considered in the evaluation, as described below.

General Site and System Descriptions

Caltrans District 2 has installed five dynamic curve warning signs with radar-measured vehicle speed incorporated into the respective changeable warning messages. The five sites, all within Shasta County, include:

1. Sidehill Viaduct, Southbound, Postmile 30.00;
2. O'Brien, Southbound, Postmile 32.30;
3. Salt Creek, Southbound, Postmile 37.53;
4. La Moine, Southbound, Postmile 49.23; and
5. Sims Road, Northbound, Postmile 57.90.

The sight distance for each CMS met or exceeded the manufacturer's specifications. Specifically, for the minimum 18-inch lettering that is being displayed on each CMS, the sign manufacturer specifies a sight distance of 1,000 feet (12). O'Brien is the only site at which the adequacy of the sight distance was questionable, due to existing obstructions. However, the actual sight distance of the CMS at O'Brien was measured to be 1,100 feet. Figure 1 shows the location of each site on Interstate 5.

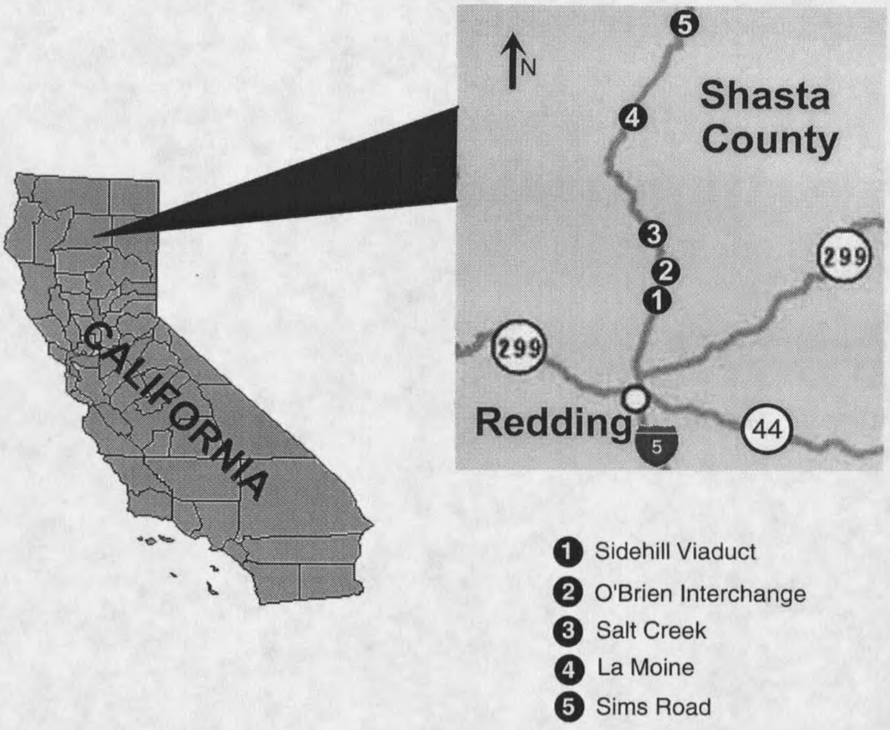


Figure 1. Site Locations in Shasta County

Sidehill Viaduct

Sidehill Viaduct is the southernmost site on Interstate 5. This is the only location where the CMS is on the left-hand side, due to the steep cut slope on the right side of the road. The curve for which this system applies is placed about one-third of the way down a 6% downgrade on a southbound divided section of I-5 (13). Figure 2 shows the Sidehill Viaduct site.