Methods and Metrics of Evaluation of an Automated Real-time Driver Warning System

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Abstract. There is significant interest by traffic management personnel in the use of automated warning systems to provide drivers with real-time information on hazardous conditions related to traffic, limited visibility or roadway obstructions. However, the effectiveness of such systems in achieving desired traffic safety improvements has not yet been well-quantified. Relative influences on traffic safety can be assessed in a large number of ways, and overall conclusions must be based upon an appropriate set of metrics and methodologies for a particular implementation. In this work, supported by the California Office of Traffic Safety and the California Department of Transportation, we build upon prior research to develop, deploy and test various metrics and methods to evaluate a large-scale real-time driver warning system, the Caltrans Automated Warning System (CAWS), installed on Interstate 5 and State Route 120 near Stockton, California. Methods include the analysis of historical accident data over an 11 year period, a direct assessment of the operational behavior of the system correlated with accident data, and a study of the direct effects of real-time warning messages on driver behavior. Instrumentation deployed to facilitate these detailed analyses is described. The resultant body of data supports the correlation of measurable traffic flow parameters with relative traffic safety.

INTRODUCTION

This paper reviews current and past deployments of systems for warning drivers on highways of hazardous fog or traffic conditions, and discusses methods used to evaluate the effectiveness of these systems. A comprehensive set of methods and metrics of evaluation is proposed, extending prior research. These methods and metrics are currently being applied to the evaluation of a complex real-time driver warning system deployed by the California Department of Transportation. Lessons learned from this process are discussed. Preliminary data and observations are presented to illustrate and explain the methods and metrics of evaluation. However, the objective of this paper is to help generate discussion and enhance cooperation in the development of acceptable practices for the evaluation of active safety improvement projects as exemplified by the CAWS. This open exchange is expected to enhance the relevance of our evaluation conclusions, and help create a common basis for comparison with results from other systems.

BACKGROUND

According to the National Highway Transportation Safety Administration (NHTSA) Fatality Analysis Reporting System (FARS), visibility-impairing fog was present and presumed a factor in 418 of the 38,309 fatal crashes that occurred nationwide (USA) in 2002 (1). Although fog crashes account for only a small percentage of all crashes, they often involve multiple vehicles and massive losses, not revealed by the raw statistics. Fog is a transient phenomena, difficult to predict and variable in density, location, dissipation rates, and area. The presence of fog creates a condition of greatly enhanced risk on a highway for which most drivers are unprepared and unable to compensate. Ultimately, driver errors, most often excessive speed and inadequate vehicle separation for the prevailing conditions, lead to chain reactions with sometimes catastrophic consequences.

The magnitude and severity of such events has motivated interest in active mechanisms intended to reduce the heightened risk during poor visibility. The most sophisticated such mechanisms are real-time driver warning systems, capable of alerting drivers in advance of hazardous conditions, and possibly recommending specific driver actions such as reduced speed. National Cooperative Highway Research Program Synthesis reports in 1976 (2), 1991 (3) and 1996 (4), among many other works, have provided primary guidance for many contemporary detection and warning system designs.
Exposure of drivers to an appropriate warning message during foggy conditions increases the time available for reaction and provides drivers with information that can improve alertness to impending hazards, such as a traffic slowdown or stoppage ahead. Reduced mean speed is the usual objective of warning interventions. There is evidence that advisory messages help to reduce variability in driver behavior, but there remains concern about differential compliance which has the potential to increase the non-uniformity of driver reactions.

One of the earliest fully-automated systems was the Roadway Safety Enhancement System deployed on the A16 near Breda in the Netherlands as part of the Drive II project in 1992. It was evaluated over a two year period 1992-94 (5). The evaluation methods used for this system, especially the emphasis on driver response, were of particular influence in the present work. The CAWS deployment was preceded by several manually-actuated systems in the US including deployments in Idaho (6), North Carolina (7) Oregon (8,9,10), Virginia (11), Tennessee (12), and previously in California (13,14). In Europe, in addition to the Dutch system, automated and semi-automated driver warning systems have been deployed in Finland (15,18), Germany (18), Australia (18), and England (16). Real-time variable speed limits have been implemented in Britain, Germany and the Netherlands for many years, and are reported to result in reduced speed variance and more uniform headways between vehicles (17). Many of these systems include provisions for activation in response to visibility conditions, although most are under manual control. A comprehensive review of systems world-wide which implement variable speed limits in 2000 was presented at the 79th TRB meeting (18).

Concurrent with or after the activation of the CAWS in November 1996, several systems have been deployed in the US, including systems in Georgia (19,20), Tennessee (21), Arizona (22) and Utah (23,24). Similar warning systems have been deployed in California (25,26), although all have relied on manual actuation. All projects have included some provision for effectiveness assessment, although data available and evaluation methods have been highly variable. Florida (27) and California (26) studies recognized the lack of quantitative results in evaluations of visibility-related driver warning systems. An editorial in the Journal of Safety Research expressed an urgent need for the identification of effective strategies for crash prevention based upon well-structured controlled trials (28).

The behavioral response of drivers to traffic management interventions of all types has been the topic of research over many years, for example (29,30,31). A consensus exists that increased speed variance, as well as increased mean speed, represent an increased accident risk. There appears to be less consensus regarding the value of various traffic safety interventions. The effects of traffic rules in general on driver behavior have been studied, one conclusion being that only rules which can be enforced should be implemented (32), suggesting that advisory speed limits may have little effect. One researcher presents compelling arguments that almost any improvement in infrastructure ultimately leads to increased traffic fatalities (33). Two evaluations of active driver warning systems have reported increased mean speeds as a result of a reduced speed warning message (6,23), with the latter of these references reporting a concurrent decrease in speed variance. Some recent work has attempted to relate available traffic data to accidents occurring in proximity to the time and location of the data measurement (34).

As reported in (27), the National Transportation Safety Board (NTSB) determined that a common cause of visibility-related crashes is the non-uniform response of drivers, especially with regard to speed. They observed that as drivers approach and enter a fog area they react in different ways, and that few studies have been done on driver behavior during poor visibility conditions. As early as 1967, it was reported that in poor visibility, mean and 85th percentile speeds usually decreased by 5-8 mph, but that some drivers continue at speeds higher than the posted speed limit (4).

THE CALTRANS AUTOMATED WARNING SYSTEM (CAWS)

The San Joaquin Valley lies in the interior of California, extending from Sacramento south to the Tejon pass, at the north perimeter of Los Angeles County. The valley is known for seasonal Tule fog, occurring from approximately October through April. Interstate Highway 5 is a major north-south traffic artery that runs the length of this corridor. It has historically been prone to multi-car accidents due to fog. In particular, the junction of southbound I-5 and westbound SR-120 is an area of high accident rates due to potentially large speed differentials and limited sight distance at the merge point.

In 1990, motivated by the expansion of State Route 120 (SR-120) connecting Interstate Highway 5 (I-5) and State Route 99 (SR-99), Caltrans proposed a multi-sensor automated warning system to improve safety in this high-traffic
area. It was known from prior studies in this area and in Riverside, California (14) that lack of driver trust could easily nullify any potential benefits. Another consideration was that fog in this area is highly localized, with dramatic visibility changes in as little as 500 feet. These criteria dictated a network of closely spaced real-time sensors for both visibility and traffic conditions, and a display system that could be seen by drivers even during limited visibility.

The result was an architecture incorporating three primary elements: a network of nine remote meteorological stations including visibility sensors, 36 traffic speed monitoring stations, and nine self-illuminated changeable message signs deployed over approximately fifteen miles of I-5 and SR-120. Each remote weather information system (RWIS) includes a dual-axis forward-scatter visibility sensor, an anemometer, wind direction indicator, barometer, thermometer, relative humidity (dew point) sensor, precipitation gauge, and a telemetry system for encoding all instrument data and transmitting to a central facility. At the time of completion and activation in 1996, the system was unique among U.S. systems in that it provided fully-automated responses to a range of hazardous roadway conditions, including but not limited to fog. The system was engineered and constructed by Caltrans Division of New Technology and Research. Subcontractors provided the weather-monitoring and communications components. Standard Type 170 controllers, Type 222 detectors, and rectangular inductive loops were used for traffic speed detection.

The primary function of the CAWS is to warn drivers in advance of reduced visibility and/or congested traffic, especially combinations of both: slow or stopped traffic ahead which drivers might otherwise not be aware of due to reduced visibility. The system incorporates a hierarchical control strategy which prioritizes and sequences warning messages in response to hazardous conditions. Individual changeable message signs can also be activated manually to warn of roadway hazards such as construction, or as part of the State-wide Amber Alert system to ask drivers to watch for specific vehicles. The system is controlled by a network of three PC-type computers located in the Caltrans District 10 Transportation Management Center (TMC). A map of the CAWS study area is shown in Figure 1.

Figure 2 shows the first CMS encountered by drivers entering the study area from the north, and the video cameras installed for verification of the CMS message and local traffic and visibility conditions.

A comprehensive independent evaluation of the CAWS was commissioned in 2000 by the California Office of Traffic Safety via Caltrans, conducted by Loragen Corporation of San Luis Obispo, California.

EVALUATION METHODOLOGY

We are evaluating the effectiveness of the CAWS in reducing traffic accidents resulting from limited visibility and congested traffic conditions. Ultimately, the evaluation sponsors hope to determine if this system and systems like it are cost-effective investments relative to other safety-enhancement options. The system complexity, the large number of external and institutional factors, and the human behavior aspects dictated a multi-level approach to the evaluation, and the development of appropriate assessment methods and metrics of performance. Four levels of evaluation were established:

End result assessment: Does the system lead to a tangible reduction in the number and severity of accidents within the range of its warning capabilities? Any conclusions must compensate for external factors such as speed limit changes, roadway construction, changes in commuting patterns and volumes, and weather history.

Operational effectiveness: Does the system function in a manner consistent with its overall design objectives and specifications? Is the control strategy adequate and/or optimal? Did the design envision all appropriate traffic scenarios? Was the intended control strategy faithfully implemented?

Reliability and maintainability: How often have components of the system been inoperable or malfunctioning, including sensors, field controllers, communications links, computational components, and display devices? How vulnerable is the architecture to single points of failure, and failures of power and communications services? How much of a burden on staff is the system to operate and maintain?
Effects on driver behavior: Do drivers comply with advisory messages, and/or respond to warning messages in ways that reduce risk? This requires the development of a better understanding of the relationship between accident risk and traffic parameters measured for individual vehicles.

Methodologies for each level of evaluation are described below:

**End Result Assessment**

We consider accident data compared over time periods prior to and after the activation of the system, as well as compared with data from similar control areas. The accumulation of a statistically useable body of data has required several years due to the relatively small geographic area under study. However, during this time, the system under test has changed significantly, weakening the validity of any comparative results. To date, we have studied historical accident data for the period five years prior to, and six years following the activation of the system, which occurred November 1, 1996.

As a primary control area, we use the opposite traffic directions in the study area, since the warning system was deployed only for one flow direction. We also use traffic statistics from areas with similar characteristics when appropriate. Accident data are normalized to total vehicle miles traveled (VMT) for each period and locality, as well as vehicle miles traveled only on days with significant fog or inclement weather. Accidents were also classified by circumstances and vehicle class, including all-weather accidents, accidents occurring in fog, accidents occurring in inclement weather, accidents occurring during roadway construction, and secondary as opposed to primary accidents.

Accident data have been obtained from the Caltrans Traffic Accident Surveillance and Analysis System (TASAS) and the California Highway Patrol Statewide Integrated Traffic Records System (SWITRS). Traffic counts were obtained from CAWS computer log files for the study direction, and from traffic count station records for the control directions. The statistical analysis package Minitab (35) has been used for most raw data analysis. The data set accumulated through 2002 contains 768 accidents prior to the deployment of the CAWS, and 1146 after deployment. Table 1 shows VMT-normalized accident totals for each year during each period, in both the study and control areas.

To assess the effectiveness of the system on accidents occurring in fog, we compared fog-day accident rates in the study and control directions normalized to fog-day VMT. Fog-day VMT differs from total VMT in that it includes only traffic occurring on days during which significant fog was present in the area, as reported by the National Weather Service and/or the CAWS RWIS logs. Figure 3 presents these results for the control and study areas on an annual basis.

An expected attribute of an active warning system is the ability to reduce secondary accidents by providing advanced warning of traffic stoppages beyond a drivers’ line of sight. Indeed, this capability is critical to the prevention of multi-car “pile-ups” often encountered in dense fog situations. Figure 4 shows annual secondary accidents normalized to total VMT in the study and control directions.

Among the other ways are examining the data is a focus on the periods of greatest recurrent risk – the morning and afternoon commuter periods. To equalize traffic volumes during peak commute hours between the control and study directions, we compare the AM commute period for one direction with the PM commute period for the other.

Over the period 1992–present, the highways under study were subject to significant changes. All traffic volumes increased, commuting patterns changed, the national speed limit increased in 1996, construction activities were frequent, and weather patterns varied. The influence of external factors on accident risk has been considered in a number of prior works, for example (36,37,38,39). Records of all construction activities during the study years have been acquired with the help of Caltrans staff. We are attempting to quantify and compensate for the influence of these external factors on traffic accidents during the before and after study periods. Two approaches are being used:

In the more simplistic method, we identify from the original accident records if a particular external factor such as roadway construction, road obstructions, or driver impairment (alcohol or drug) was present. We then “excuse” these accidents as potentially being more influenced by external factors than by the presence or non-preservation of the warning system, thus removing these from the data set. This view assumes that accidents in which unusual roadway
conditions or drunk driving were cited as factors were outside the scope of effectiveness of the driver warning system, a premise that is arguable.

An alternative approach involves attempting to model the effects of all influences on accident rates using one of several possible statistical models. SAS (Statistical Analysis System) (40) is used to generate model coefficients that achieve the best fit of the model to the available data and assumptions. This approach has often been used in prior assessments of highway accident risk (36). The key advantage of this method is that the relative influences of each factor, including the presence or non-presence of the CAWS, are revealed directly from the sign and magnitude of fitted model coefficients. A weakness of this approach is the force-fit of many different phenomena affecting accident risk to the same model, such as a linear or negative binomial relationship. This analysis remains in progress at this time.

For both methods, the choice of appropriate control areas is highly influential on the results.

**Operational Effectiveness**

We assess the operational effectiveness of the system by monitoring the response of the system to trigger events such as fog or traffic congestion. Primary data is provided by the computer log files automatically created by each of the three computers comprising the CAWS control system, and from our data acquisition equipment at three sites inside the CAWS and two control sites just prior to the north entrance to the CAWS area. We examine each activation event, and also situations in which the system should have activated. In cases where the CAWS does not respond as expected, we attempt to determine the reason. This has ultimately required the examination of the software source code to reveal the control algorithms, since adequate documentation of the system control strategy is not available.

By comparing traffic and weather data records with CMS activation records, a number of anomalies have been observed. Subsequent examination has revealed a number of design oversights and software errors affecting the driver warning functions of the system. Most of the operational issues manifest as failures to properly activate, which reduce system effectiveness but do not, in themselves, have a negative effect on traffic safety. The potential for reduced driver confidence in the system may be significant, however, which is examined in the driver behavior experiments to be discussed later. Over the course of this study, a number of institutional issues have been revealed in the design and deployment process, for example, the need for a more formal process for software development, testing and documentation prior to and after deployment.

**Reliability and Maintainability**

By direct monitoring as well as examination of the CAWS system logs, it has been possible to track the periods of proper and improper function of most system components. To date, the following components have been found to be problematic, ordered according to approximate frequency and severity of problems:

1. Inductive loop detectors
2. System communications
3. Visibility sensors (including calibration issues)
4. System power
5. Temperature / relative humidity sensors (required for fog detection)

Other than the software-related issues discussed above, few problems have been observed with the CAWS central computers, field controllers, and changeable message signs. The overall system has functioned almost continuously since November 1996. It is worth noting that much more is expected from the above-mentioned components since they serve as the sensors for an automated-response system rather than just for general traffic data collection. This has required greater attention to proper calibration and setup, which has meant greater demands on maintenance personnel.

We are also examining written service records and interviewing district personnel in an attempt to estimate the ongoing cost of operation and maintenance of the system. Cost data will be normalized to metrics of the size and capability of the system, such as the number of miles of highway served and/or annual VMT in the service area.
Effects on Driver Behavior

As previously referenced (27), the non-uniform response of drivers in the presence of limited visibility is a potential precursor to collisions. See also (4). This hypothesis is of particular importance in the evaluation of the CAWS or any active driver warning system. The system “actuators” are advisory messages intended to elicit a particular uniform response from drivers, e.g., conformance with an advisory speed limit. We attempted to design a controlled experiment to assess driver responses to messages displayed by the CAWS by comparing traffic flow data prior to and after exposure to the messages. Our approach is similar to that utilized in evaluations performed in the Netherlands (5) and Utah (23). We measure and record the exact speed, time of arrival and vehicle length for every vehicle prior to and after viewing the first CMS of the north approach to the CAWS. Vehicle speeds are recorded to a precision of 0.1 MPH (0.16 KPH), time of arrival to 0.1 second, and separations between vehicles derived from the three raw measurements to a precision of one foot (0.305 meter).

The roadway topology was advantageous – there is a small rise approximately 0.5 mile prior to the first CMS which obscures the CMS from driver view. Two “pre-view” monitoring sites were located just prior to the hill, at 1.2 and 1.3 miles ahead of the CMS respectively. Two “post-view” sites monitoring sites were located after the CMS at distances of 0.50 miles and 1.1 miles respectively, both well ahead of the viewing zone of the next CMS in the CAWS. The number of lanes (three), roadway grade, proximity of on/off ramps, and surrounding visual landscape are nearly identical at all four sites. Baseline traffic volumes at all sites are usually nearly identical, as confirmed by data acquired during normal conditions (conditions other than those that should cause the activation of a warning message). This configuration isolates to the maximum practical extent the exposure of drivers to the CMS message as an independent variable.

Specialized instrumentation is deployed at all sites to acquire individual records for every vehicle in each of the three lanes. One each of the pre-view and post-view sites includes a reference visibility sensor to provide an indication of the local visibility conditions. A fifth monitoring site is co-located at the CMS to monitor communications with the CMS, and observe the actual CMS display as well as the local traffic conditions via two network video cameras. Included in the view of the latter camera is a set of visibility test targets at known distances to provide redundant verification of visibility reported by the fog sensors at each end of the test section.

The field data acquisition systems are industrial PC platforms running real-time Linux, with watch-dog timer auto-reboot capabilities. Redundant local data storage is implemented with flash-ROM drives and battery-backed RAM, and periodic hard disk backup. All field units communicate continuously with a central server, transferring data via a redundant protocol which assures against data loss or corruption. A MYSQL (41) open-source distributed database is used, configured to maintain redundant data entries on both the central server and the field unit, with retirement of data from the field unit after positive confirmation of data integrity on the server. Redundant power (local utility with 8-hour battery backup) and communications (CDPD wireless and leased land lines) are provided to all sites. In the event of loss of communications (both CDPD and land line), all field system have the ability to store data locally up to two months, and “catch up” data transfer when reconnected. In the event of a power loss or other source of a major system failure, project personnel are automatically notified by text messaging to a cell phone to permit rapid response field servicing. The locations of the five evaluation test sites are shown on the map of Figure 1, and a more detailed diagram of the five evaluation sites is shown in Figure 5. All real-time data and camera views can be observed by the public on the Web at http://caws-evaluation.loragen.com.

This experimental apparatus permits us to analyze traffic characteristics on a vehicle-by-vehicle basis, over all visibility and traffic conditions. Conclusions about the effectiveness of the CMS messages are drawn from the degree of compliance with an advisory (e.g., if advising 45 mph, do drivers slow to 45 mph?), and from an assessment of metrics known or assumed to be indicators of relative traffic safety before and after drivers have viewed a warning message. Among these metrics are mean speed, speed differential lane-to-lane, overall speed variance (measured as sample standard deviation), proximate speed variance, intra-platoon gap, time-to-collision (TTC), and several indicators based on vehicle separation-speed relationships.

Proximate speed variance differs from variance measured over the entire event in that it considers only the interactions between vehicles whose movements can potentially affect each other due to their physical and temporal proximity. This type of variance measurement may be of greater relevance to traffic safety since it focuses on speed differences between vehicles that could potentially be involved in collisions and ignores differences between
vehicles which have no possibility of interaction. It also permits the observation of changes over relatively short periods of time. TTC is also of direct relevance to safety risk, as suggested first in (5) in which it is used in a way analogous to speed variance between proximate platoons. Intra-platoon gap considers only the separation between vehicles in each platoon rather than the typical time-average gap measurements provided directly by the “off-time” of a loop detector operating in presence mode.

Among the metrics of potential accident risk or severity we are using is potential collision speed (PCS), the estimated speed of impact \( v_{impact,i} \) in a potential collision between consecutive vehicles \( i-1 \) and \( i \) in the same lane, given the separation and speed of each vehicle. This approach considers the range of possible collision scenarios, from collision during normal braking by both vehicles to collision with a suddenly immobile object – characteristic of a multi-car collision in fog in which sight distance is less than the vehicle separation. This latter case is appropriate for assessments during dense fog conditions:

\[
\text{PCS}_i = \frac{v_{0,i}}{\min\{x_{vis,i}, x_{gap,i}\} - x_{react,i}}, \quad \min\{x_{vis,i}, x_{gap,i}\} \geq x_{react,i} \\
\text{PCS}_i = \frac{v_{0,i}}{x_{brake,i}}, \quad \min\{x_{vis,i}, x_{gap,i}\} < x_{react,i} \\
\]

\( x_{gap,i} = (t_{0,i} - t_{0,i-1})v_{0,i-1} \) = separation between vehicle \( i \) and \( i-1 \)

\( x_{react,i} = t_{react}v_{0,i} = \text{reaction distance of vehicle} \ i, \quad t_{react} = \text{driver reaction time} \)

\( t_{0,i} \) and \( t_{0,i-1} \) are the detection times for each vehicle

\( x_{brake,i} = \frac{v_{0,i}^2}{2gk_{friction}} = \text{braking distance of vehicle} \ i \)

Time, distance and velocity are in any set of consistent units. The square of PCS may be considered an indicator of the potential collision severity, since it is proportional to the kinetic energy release during an inelastic collision. In our analysis we used \( t_{react} = 0.75 \) seconds and \( k_{friction} = 0.5 \), a typical average for good tires on moist but not rain-soaked pavement. PCS can also be normalized to the initial vehicle speed, which decouples it from the effect of speed:

\[
\text{Normalized PCS}_i = \left( \frac{v_{impact,i}}{v_{0,i}} \right) 100\% 
\]

Figure 6 shows the time history of a typical CAWS fog activation episode. The abscissa is clock time in the AM. ‘Before CMS’ and ‘after CMS’ readings are reported as the average of the two pre-view and the two post-view sites, respectively. Centered 45-second moving averages are used to establish trend lines through the data cloud for PCS (upper two traces), mean speed (middle two traces) and proximate standard deviation of speed (lower two traces). Visibility is reported as extinction coefficients measured at the before and after sites. The level of the warning message (“Dense Fog Ahead, Advise 45 MPH” or “…30 MPH”) displayed by the CMS is indicated by the levels at the bottom of the plot: level = 0 means no warning message, level = 20 means “…ADVISE 45”; level = 40 means “…ADVISE 30 MPH”. A single trace indicates the average traffic volume at all sites, since volumes differed very little between sites. The CAWS response is delayed by three to six minutes because the central computers communicate with field elements using three-minute polling cycles, yielding delays of up to three minutes for sensor data acquisition, plus another three minutes for CMS activation.

During most of this event, visibility after the CMS was significantly worse than visibility before the CMS, which is not untypical of the fog in this area. As with almost all visibility-related events observed to date, PCS, mean speed
and proximate speed variance (reported as standard deviation) at the before and after sites were nearly identical prior to the event. The CMS is activated based on visibility measured at the after site, which is the first weather station in the CAWS. Speed advisories of 45 and then 30 mph were displayed corresponding to visibility thresholds of 500 and 200 feet respectively. During a brief period in which visibility dropped below 100 feet (extinction coefficient > 160), no message is displayed due to an error in the Signview control program. As visibility worsened at the ‘after’ site and the CMS activated, mean speed dropped from approximately 70 mph at the before site to 65 mph at the after site. There was no significant difference in proximate speed variance. Mean speed at the before site eventually dropped below 65 mph as the visibility at this site became worse. The reduced mean speed at the after site did not significantly change during the period in which the CMS went blank. The relative influence of the 45 mph vs. the 30 mph advisory is unclear. Advised to reduce speed to either 30 or 45 mph, drivers continued at approximately 65 mph at the after site. PCS at the after site is reported higher for most of this event due to the dependency of PCS on the visibility-limited sight distance, which was shorter at the after site for most of the event. During a brief period in which visibility was nearly identical before and after the CMS, PCS was nearly equal despite the advisory message.

It is clear that drivers reduce their speed, although not significantly, in response to reduced visibility. Some additional influence on mean speed may be attributed to the effect of the warning message. However, this influence was not sufficient to reduce potential accident severity as indicated by PCS. Similar observations have occurred for all other complete events recorded to date. A key lesson learned in this part of the evaluation was the importance of examination of the detailed time history of each event, rather than reliance on aggregated statistics which might otherwise lead to incorrect conclusions.

PROJECT STATUS AND LESSONS LEARNED

The evaluation of the system remains in progress, with formal data collection scheduled to be concluded June, 2005. However, the monitoring system will remain in place indefinitely, and continue to acquire data in support of ongoing study of driver behavior and the relationship between traffic flow characteristics and accidents.

We have found that a comprehensive evaluation of effectiveness requires assessment at four levels: analysis of long-term accident statistics; operational effectiveness assessment based upon observation system responses; reliability and maintainability assessment; and study of driver behavior in response to CMS warning messages.

The assessment of driver response to warning messages required the design of an experiment in which the effect of the message can be best isolated from other influences. We deployed multiple monitoring sites both before and after the first CMS of the CAWS to best achieve the required experimental conditions. Individual vehicle speed and time of arrival records are required to adequately characterize traffic flows for this purpose, since they permit a detailed examination of each activation event rather than reliance on metrics aggregated over long time periods.

Final conclusions regarding the CAWS effectiveness will not be considered valid until the reduction of all available data at the completion of this multi-year evaluation.

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Figure 1. CAWS deployment on Interstate 5 and State Route 120 near Stockton, California. Evaluation monitoring sites are at the north entrance to the study area.
Figure 2. CMS 1 and traffic and message verification cameras. Field data acquisition equipment is in Type 334c cabinet at bottom right.
Figure 3. Annual fog-day accident rate normalized to fog-day MVMT, study vs. control direction. (MVMT = Million Vehicle Miles Traveled)
Figure 4. Normalized annual secondary accident rate, study vs. control direction.
Figure 5. Five test sites for evaluation of driver reaction to CAWS advisory messages.
Figure 6. **Normalized PCS, mean speed and proximate speed standard deviation, before and after drivers view a speed advisory message during a dense fog episode.**