

Field Evaluation of Work-Zone Automated Speed Enforcement Equipment and Traffic Monitoring Devices

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ABSTRACT

Speeding is a significant contributor to a significant portion of highway collisions. For work zones in particular, the speeding problem is compounded by on-site road re-configuration, narrowed lanes, or poor visibility. Automated speed enforcement is one potential solution to reduce the number of collisions in roadway zones where speeding is a persistent problem. This paper describes a recent study that is designed to assess the technical performance of work-zone automated speed enforcement (ASE) equipment in the field. Several traffic monitoring systems were field tested with an ASE system at a rural two-lane highway. The ASE equipment and other devices were found to detect 2-5 % of passing vehicles to travel in excess of 65 mph in a highway with a posted speed limit of 55 mph. The outcome of this study, in conjunction with the experience and knowledge gained by other agencies in their development and implementation of work-zone and general ASE systems will provide valuable inputs for future safety projects.

1.0 INTRODUCTION

Speeding is a significant contributor to a significant portion of highway collisions. For work zones in particular, the speeding problem is compounded by on-site road re-configuration, narrowed lanes, or poor visibility. As part of the efforts to seek safety improvements of the California highway network, the California Department of Transportation (Caltrans) is exploring the implementation issues of automated speed enforcement (ASE) and sponsoring a project conducted at California PATH¹, University of California at Berkeley.

An earlier phase of the project was carried out and concluded with an extensive literature review and an examination of various institutional and legal issues involved in the implementation of ASE [1]. In the earlier report, the legal restrictions to the implementation of automated speed enforcement in the U.S. were outlined. An evaluation of key program design choices was also provided, encompassing a variety of issues. In the current, second phase of the project, more emphasis is placed on the technological evaluation of ASE equipment. A work-zone ASE system was acquired and installed in a field experimental site, along with several other commercially-off-the-shelf traffic monitoring devices. The objective of the study is to examine the field performance of the equipment in a real-world setting, when evaluated against other traffic sensing devices. This paper provides a description of the rationale behind the study, the equipment included in the study, and the findings from the field experiment.

2.0 A CASE STUDY OF RURAL HIGHWAY SAFETY

A state highway (SR-12) in Northern California was chosen as a case study for this project. This highway is a rural roadway, which serves as a corridor connecting several counties and two interstate highways and one major state highway. It spans over 185 kilometers (115 miles), with one lane in each direction during a majority of its length and two lanes in each direction where it is closer to the junctions with other highways. The traffic pattern exhibited a high percentage of

¹ www.path.berkeley.edu

speeding vehicles and frequent serious collisions. In order to understand the contributing factors and the collision patterns, the historical data of crash records were analyzed for a 5-year period of 2002-2006.

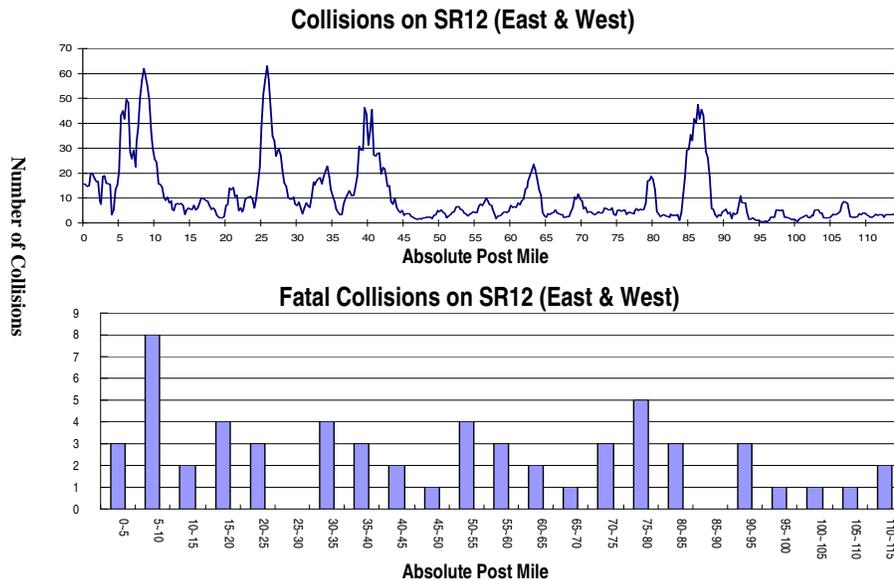


Figure 1 All Collision and Fatal Collisions along SR-12, 2002-2006

single(0)/multiple(1)|(All)|Year|(All)|severity|(All)

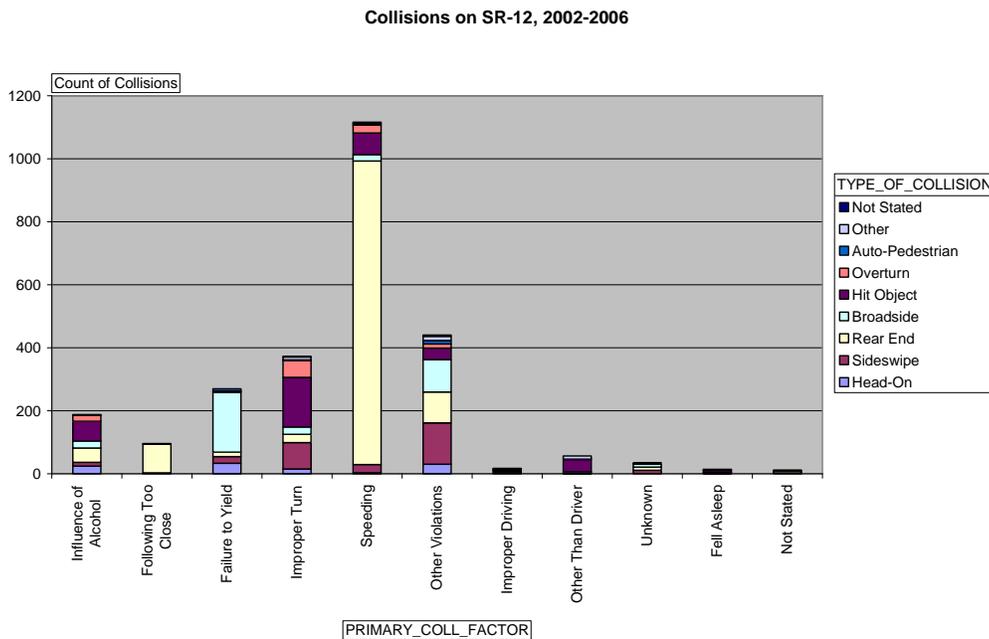


Figure 2 Primary Collision Factors and Collision Types of SR-12, 2002-2006

Figure 1 depicts the distribution of all and fatal collisions along the whole stretch of SR-12 over the 5-year period. Figure 2 shows the counts of collisions by the primary collision factors as reported in police reports in the same period. Unequivocally, speeding is an apparent cause of many crashes. In conjunction with the collision data analysis described above, a recent traffic survey was carried out in October 2007 by using on-site surface traffic sensors to acquire traffic counts, speed and vehicle class distribution. Figure 3 displays the exemplar data of vehicle speed and class distribution in a 24-hour period.

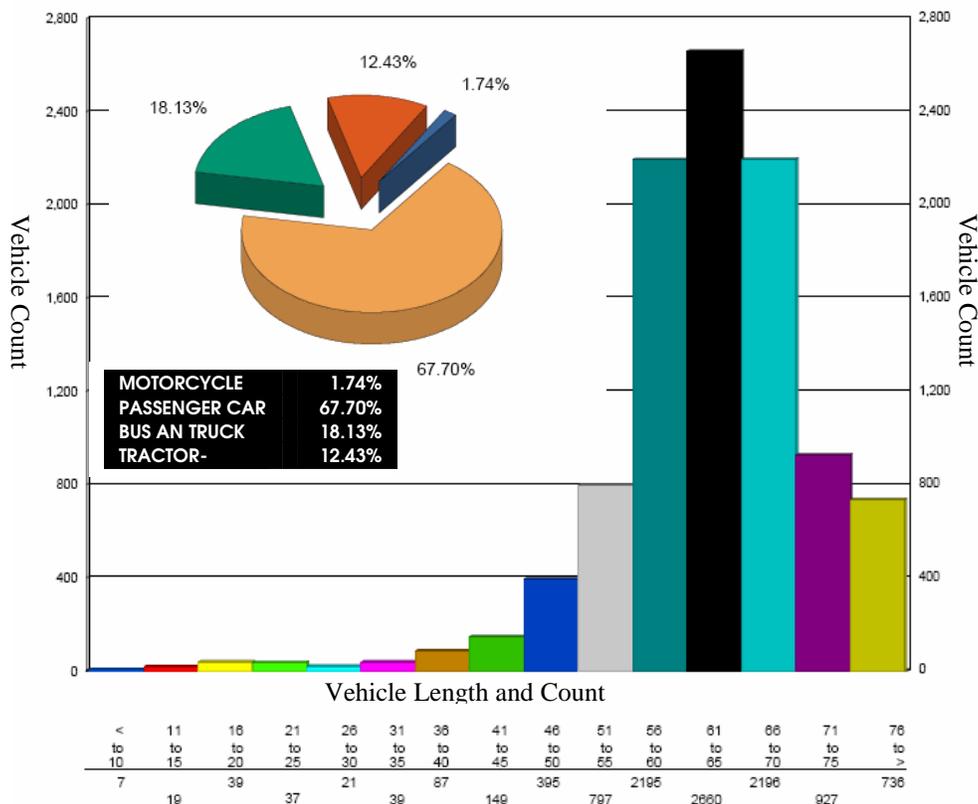


Figure 3 Vehicle Class and Speed Distribution in a One-Day Period on SR-12

3.0 TECHNICAL EVALUATION OF ASE EQUIPMENT

With the advancements in sensing and communication technologies, a variety of traffic monitoring devices are becoming more affordable and feasible. For the purpose of implementing ASE as well as other traffic measurement devices, it is important for traffic practitioners and highway operators to define and to understand the performances of such equipment. More importantly, selective components and sub-systems can be potentially integrated to provide traffic enforcement and management functions more economically and effectively. Therefore, one major objective in the current study is to conduct a comparative evaluation of several candidate traffic monitoring systems so that their field performance can be fairly and thoroughly

investigated. In the meantime, by testing ASE equipment in a field setting, insights can be gained through experimentation to provide inputs for law enforcement agencies and local jurisdictions.

3.1 Performance Metrics for ASE Equipment

A preliminary set of performance measures for the evaluation of automated enforcement functions is outlined in Table 1. The final performance metrics can be determined for a specific equipment model, based on its design characteristics, and the operation environment that it is intended for. The performance measures are designed to serve as an evaluation tool for the selection of automated enforcement systems when safety countermeasures are considered. Detailed specifications and criteria can be refined according to the configurations of a particular device or the setting of field experiments.

Table 1 Performance Measures of Automated Speed Enforcement Equipment

Category of Measures	Specific Measures	Exemplar Criteria Description	
Long-term service contract requirements			
Ease of Operation (Assuming independent operation)	Setup Required	Procedures, requirements, and accessories for field setup	
		Pre- and in-the-field calibration	
		Parameter-changing procedures	
		Remote-connection tuning or adjustment	
	Diagnostic and Verification Tools	Tools for setup, calibration, and verification	
	Level of Training Required, and Learning Curve	Operational handbook and manual availability	
		Required training for equipment upgrade or update	
Operational Capability and Robustness	Speed and Distance Accuracy	Threshold speed and tolerance range	
	Field of View	Maximum distance and angular coverage	
	Environmental Sensitivity	Temperature, humidity, rain, snow, wind, etc.	
	Photography		Resolution
			Frequency
			File size
		Storage capacity	
	License Plate Recognition		Error Rate
			Range of recognized symbols and characters
	Availability and Reliability		Average time between malfunctioning
			Indicators for equipment status
			Degraded mode operation
			Restoration procedures

		Ease of repair
		Availability of service
	Integration with other devices	Output message format and contents
		Output message protocol
		Output message file size
		Interface types
		Indicator of missed transmission
Flexibility in Operation	Equipment options	Choice of options
		System architecture flexibility and openness
		Remote access by networked connection
		Procedures in temporary shutdown and rebooting

3.2 Experimental Data Collection Plans

Commercially-off-the-shelf traffic sensors were selected that could potentially offer comparative output for the evaluation of ASE equipment. The combined sensor suite was deployed at selective locations along the case-study highway. The data collection sites were chosen preferably to allow field data collection with variations in setup configurations and traffic patterns. At each location, the data collection process continued for approximately one week. During the course of the field observation, data were collected for comparative evaluation but no enforcement function was executed.

In a separate project, the research team has surveyed and tested a number of commercially-off-the-shelf traffic monitoring devices for a different application [2-4]. Based on previous experience of evaluating such products, a selective set of candidate products were acquired and developed for the current task.

3.3 Traffic Monitoring Devices



Figure 4 Devices Used in Data Collection for Technical Evaluation

For the data collection task, an industrial computer (PC-104) system was developed and interfaced with a traffic monitoring radar and an ASE equipment to record synchronized data. Four different types of sensors shown in Figure 4 were combined into one sensor suite.

The sensor suite used in the field included:

- Road Working Area Safety System (RWASS manufactured by *Sensys Traffic*² AB, Sweden, and provided by Road-Tech, a subcontractor to California PATH in this project.
 - The Road Working Area Safety System (RWASS) is designed to operate in a work zone, based on the Mobile Speed Safety System.
 - It warns drivers for excess speeding, alarms road workers of potentially dangerous situations, and enforces should the speeding driver choose not adapt to the applicable speed limit.
 - It reports the time, speed, distance, and direction of the target. Besides using a radar sensor to detect speeding targets, it is also equipped with a camera to capture the image of violators.
 - RWASS is equipped with photograph capabilities to record events triggered by speeding vehicles. However, **the camera was disabled** during the field tests to alleviate privacy concerns. The triggering signal was kept active to provide synchronization pulses to the PC-104 for the data-acquisition process.
- EVT-300TM (*Eaton-Vorad Technologies*)³ Tracking Radar
 - The 24-GHz EVT-300 is offered by Eaton-Vorad that utilizes mono-pulse radar⁴ technology in conjunction with state-of-the-art digital signal processing.
 - This is target-tracking radar functioning as part of a forward-looking collision warning system. It is mainly developed and used by freight vehicles to alert drivers of imminent collisions. In the year of 2007, a newer version of radar, VS-400, came to the market and the older version is no longer available off the shelf. In this study, it is still applicable and the radar was included to acquire target data to be compared with those outputs by RWASS.
- Nu-Metrics NC-200TM (*Quixote Technology*)⁵ Traffic Sensors
 - NC-100/200 is a portable traffic analyzer designed to be placed directly in the traffic lanes to provide traffic data.
 - The NC-100/200 utilizes Vehicle Magnetic Imaging to detect vehicle count, speed and classification.
- Trans-QTM (*Quixote Technology*)⁶ Radar Traffic Classifier
 - The *trans-Q* is designed for non-contact measurement of traffic flows.
 - It utilizes a Doppler radar to detect traffic count, speed, and length.

² <http://www.sensys.se/>

³ <http://www.roadranger.com/Roadranger/productssolutions/collisionwarningsystems/index.htm>

⁴ http://en.wikipedia.org/wiki/Monopulse_radar

⁵ <http://www.qttinc.com/pages/nc200.html>

⁶ <http://www.qttinc.com/newproducts/trans-Q.html>

- It is capable of reporting traffic data for two-direction roadways with one lane in each direction.

3.4 Equipment Configuration and Layout

A schematic diagram in Figure 5 depicts the arrangement of equipment.

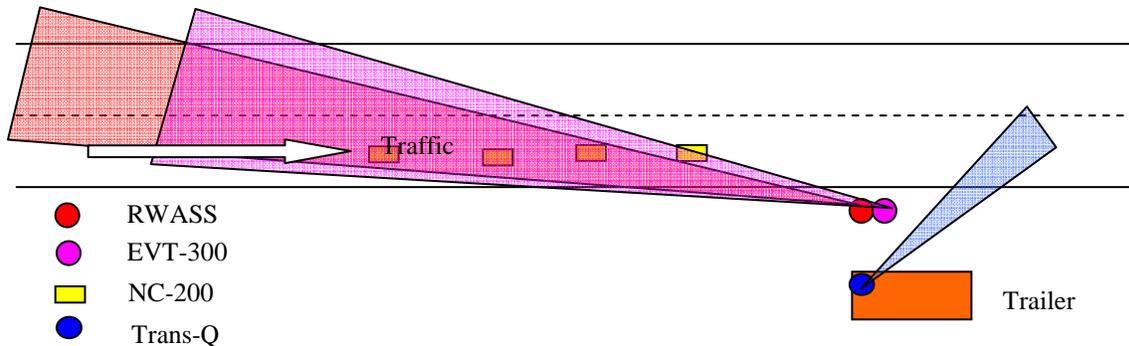


Figure 5 Layout of Equipment Setup at Data Collection Site

- RWASS and EVT-300 were set up on roadside, as close to the traffic lane as possible. The radar antennas were oriented to the upstream direction to cover oncoming traffic.
- A trailer equipped with solar panels and batteries was located further from traffic lanes, but sufficiently close to provide power supplies to RWASS and EVT-300.
- A data acquisition computer was stored inside the trailer box. A synchronization signal is provided by RWASS to EVT-300 data computer whenever RWASS was triggered by a speeder traveling over the pre-determined threshold.
- Trans-Q was mounted on a pole attached to the trailer. The radar was configured to target the traffic flow at 45 degrees. This unit is oriented in a direction opposite from the other two radar due to concern of potential electro-magnetic interference because both Trans-Q and RWASS are operating at 24.125 GHz. The trans-Q lateral position was located within 30 feet from the centerline of the near traffic lane.
- Four NC-200 devices were installed on the near lane using adhesive tapes. The four sensors were arranged sequentially to acquire data at different distances relative to the radar location.

4.0 SUMMARY OF FIELD DATA ANALYSIS

This section provides a summary of data that were collected in the field from Route 12. The data presented here was from one week of field observation in July 2008, but only selective data sets were explained and illustrated below due to the limitation of space. At this site, the posted speed limit was 55 mph. The range of traffic volume at the data collection site was 8,500-9,500 vehicle count per day.

4.1 RWASS

RWASS was activated throughout the collection period of one week. However, only 4-plus days of data were collected due to vandalism and loss of power supply. Out of 22,849 targets detected by RWASS, the system registered 671 times (2.9%) of speeding records for vehicles traveling at 65 mph or higher. The triggering threshold for RWASS was set at 65 mph, 10 mph higher than the speed limit, to take into account that the traffic flow in this region generally moves at a speed higher than the speed limit.

Figure 6 shows the measured speed of targets detected by RWASS on July 16. The left chart plots the instantaneous speed of each passing target when the target is 32 meters (106 feet) from the radar antenna. Generally, RWASS begins tracking targets from a range of 100 meters. The right chart depicts the distribution of speeds among all targets on the same date.

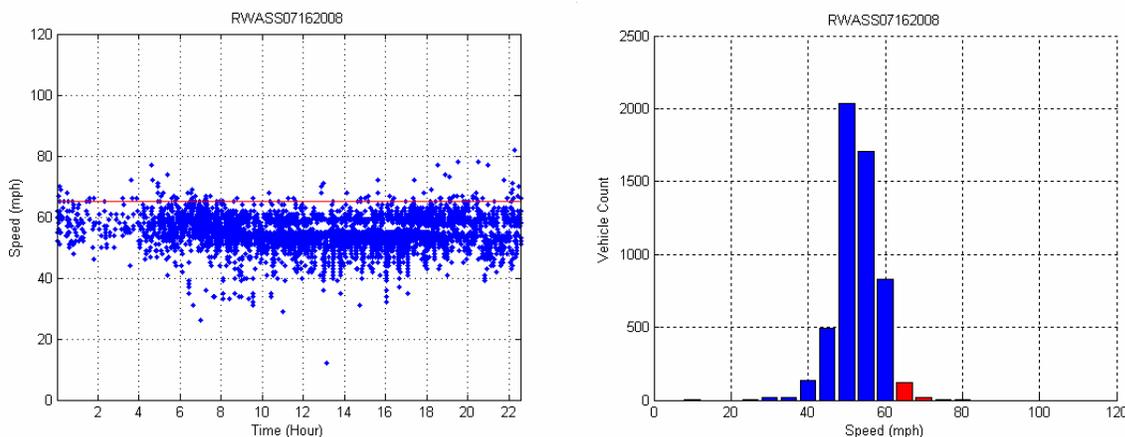


Figure 6 RWASS - Speed of Passing Vehicles in One Day and Overall Distribution

Table 2 lists the total vehicle counts for 5 days and the percentage of speeders. Note that on the column of July 20 (Sunday), the system was only powered for the midnight and early morning hours, thus the vehicle count was low. However, the ratio of speeders in this nighttime period was quite high. Additionally, the total and speeder counts are also listed for the night time hours, midnight o 6 in the morning. There is a significant increase in the ratio of speeding vehicles during this period.

Table 2 RWASS Vehicle Count with Percentage of Vehicle Traveling at Speed of 65 mph or Higher

Date	07-16	07-17	07-18	07-19	07-20*
Vehicle Count	5373	5471	6124	5560	321*
Vehicle Counts of Speed > 65 mph	144	130	131	221	45*
Percentage of Counts > 65 mph	2.68%	2.38%	2.14%	3.97%	14.00%*
<i>Night time (Hours 0-6)</i>					
Vehicle Count	402	380	406	308	273
Vehicle Counts of Speed > 65 mph	32	27	38	41	38

Percentage of Counts > 65 mph	7.96%	7.11%	9.36%	13.31%	13.92%*
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4.2 SR-12 Caltrans Traffic Station

Caltrans has a traffic monitoring station near Post-Mile 5.6 of Route 12, close to the data collection site. At this station, a pair of in-ground loops is spaced by 12 feet (3.6 meters) with a piezoelectric sensor in between. The double loops and the piezoelectric sensor are combined to provide vehicle count, speed measurement, vehicle length, and axle spacing for each passing vehicle. The data collected data from this station were used to compare to those measured by other sensing devices on the eastbound lane.

An exemplar set of data from one day (July 16) is illustrated below. Figure 7 displays the measured speed of each passing vehicle on the left chart and the speed distribution on the right. For this particular day, 274 out of 8499 (3.22%) vehicles were passing at speed higher than 65 mph (29.1 m/sec).

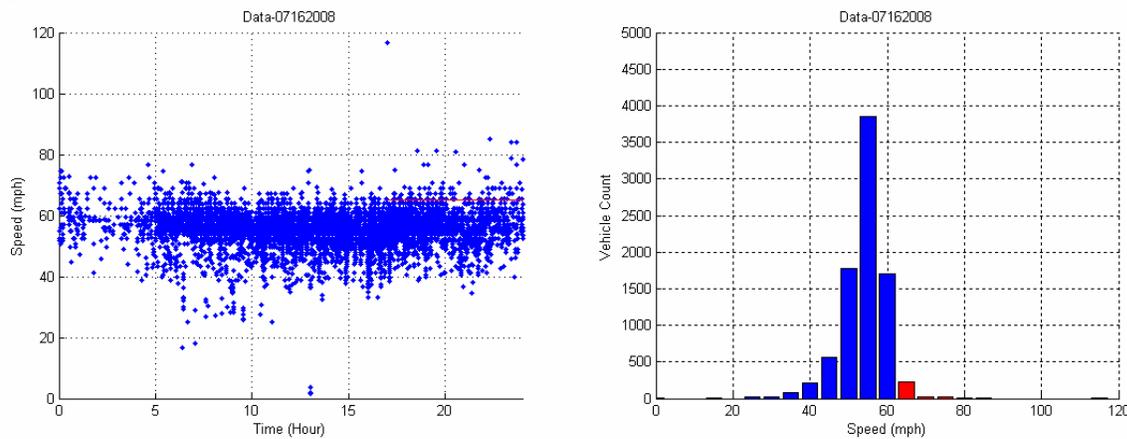


Figure 7 Caltrans - Speed of Passing Vehicles in One Day and Overall Distribution

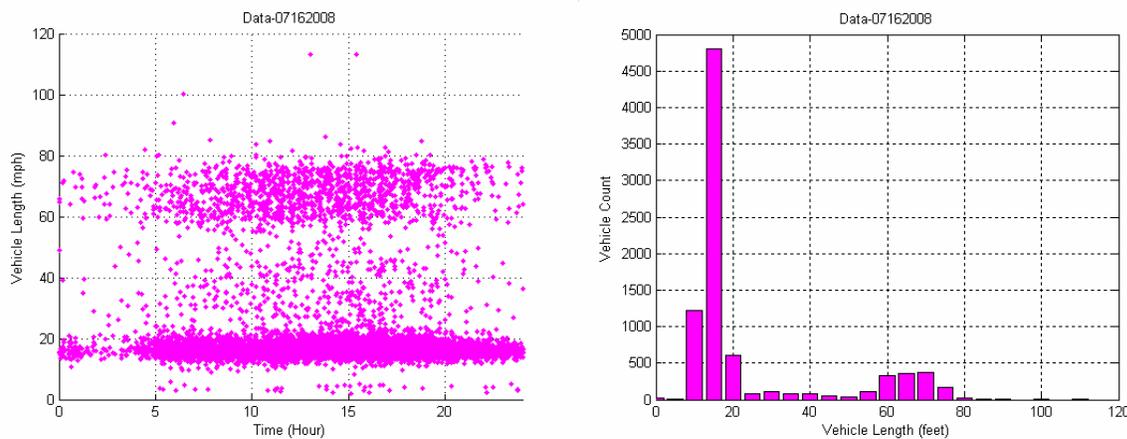


Figure 8 Caltrans - Length of Passing Vehicles in One Day and Overall Distribution

Figure 8 displays the measured vehicle length of each passing vehicle on the left chart, with the length distribution shown on the right graph. For this particular day, 1550 out of 8498 (18.24%) vehicles were has a length greater than 40 feet (12.2 m/sec), indicating a significant ratio of heavy-duty vehicles on this route.

The Caltrans traffic station was activated throughout the study period, but was intermittently turned off for maintenance reasons for the later part of the week. Table 3 shows the vehicle counts and the percentage of speeders for 5 consecutive days. Note that in the last two columns, for July 19 (Saturday) and July 20 (Sunday), the percentages of speeding vehicles are much higher than the other days. In particular, the ratio of speeding vehicles is the lowest on Friday, when the traffic was the heaviest. Additionally, the total and speeder counts are also listed for the night time hours, from midnight to 6 o'clock in the morning. There is a significant increase in the ratio of speeding vehicles during this period.

Table 3 Caltrans Vehicle Count with Percentage of Vehicle Traveling at Speed of 65 mph or Higher

Date	07-16	07-17	07-18	07-19	07-20
Vehicle Count	8499	8861	9732	8898	7127
Vehicle Counts of Speed > 65 mph	274	272	243	452	366
Percentage of Counts > 65 mph	3.22%	3.07%	2.50%	5.08%	5.14%
<i>Night time (Hours 0-6)</i>					
Vehicle Count	466	454	515	408	350
Vehicle Counts of Speed > 65 mph	57	46	57	69	62
Percentage of Counts > 65 mph	12.23%	10.13%	11.07%	16.91%	17.71%

4.3 NC-200

Four NC-200 surface sensors were mounted in sequence on the eastbound lane at the test site at Positions A-D. Position A was approximately 10 meters west of RWASS, and B, C, And D are further upstream along the approaching traffic lane in approximately equal spacing. Sensor D was damaged during the experiment, thus only data from the other three are shown. In Figure 9, the distribution of measured speeds and vehicle lengths are given for July 16, the same day as those illustrated in the section above. Among the three sensors, Sensor B appears to contain abnormal and offset data, probably due to installation errors or device malfunctioning. Position C was found to have the most consistent and best matching data when compared with the Caltrans Data Station.

Table 4 shows the vehicle counts and percentage of speeders with data from Sensor C for 5 days. The ratio of vehicles traveling at 65 mph or higher ranges between 2.30% to 4.30%. The weekend days have higher ratios, and Friday again exhibits the lowest ratio with the highest traffic volume.

Table 4 NC200 – Position C - Vehicle Count with Percentage of Vehicle Traveling at Speed of 65 mph or Higher

Date	07-16	07-17	07-18	07-19	07-20
Vehicle Count	8457	8769	9658	8793	7739
Vehicle Counts of Speed > 65 mph	271	255	222	368	333
Percentage of Counts > 65 mph	3.20%	2.91%	2.30%	4.19%	4.30%

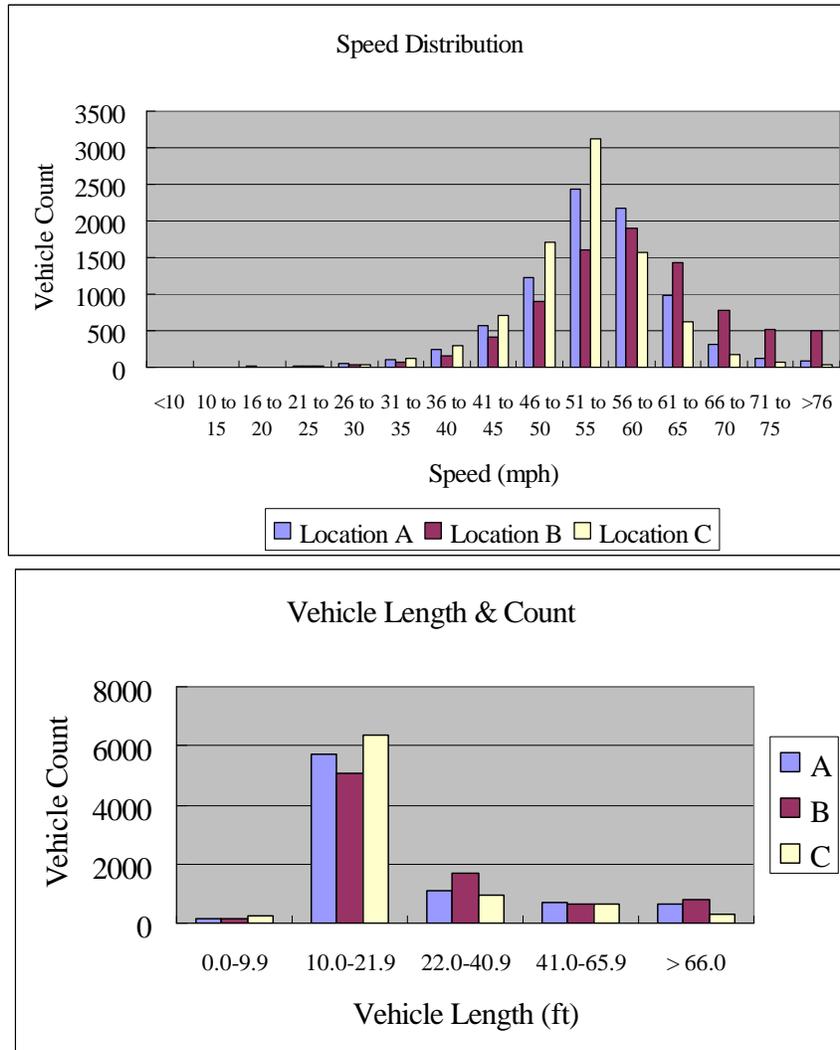


Figure 9 NC200 - Distribution of Vehicle Speed and Length in One Day

4.4 Trans-Q

Trans-Q is capable of detecting traveling targets in two directions in a two-lane highway. During the field experiment, Trans-Q was oriented in an opposite direction from RWASS to avoid

electro-magnetic interference. In Figure 10, the data of July 16 as those in previous sections are plotted for both eastbound and westbound lanes. The eastbound data from Trans-Q correspond to those measured by the other devices. Overall, Trans-Q appeared to have under-estimated the speeds of passing vehicles, and the speed distribution is shifted to the left side of the scale.

Table 5 shows the vehicle counts and percentage of speeders with eastbound-lane data from Trans-Q for 5 days. The ratio of vehicles traveling at 65 mph or higher ranges from 0.35% to 0.88%. This range is considerably lower than those from the other measurement systems. However, the weekend days still have higher ratios, and Friday again exhibits the lowest ratio with the highest traffic volume.

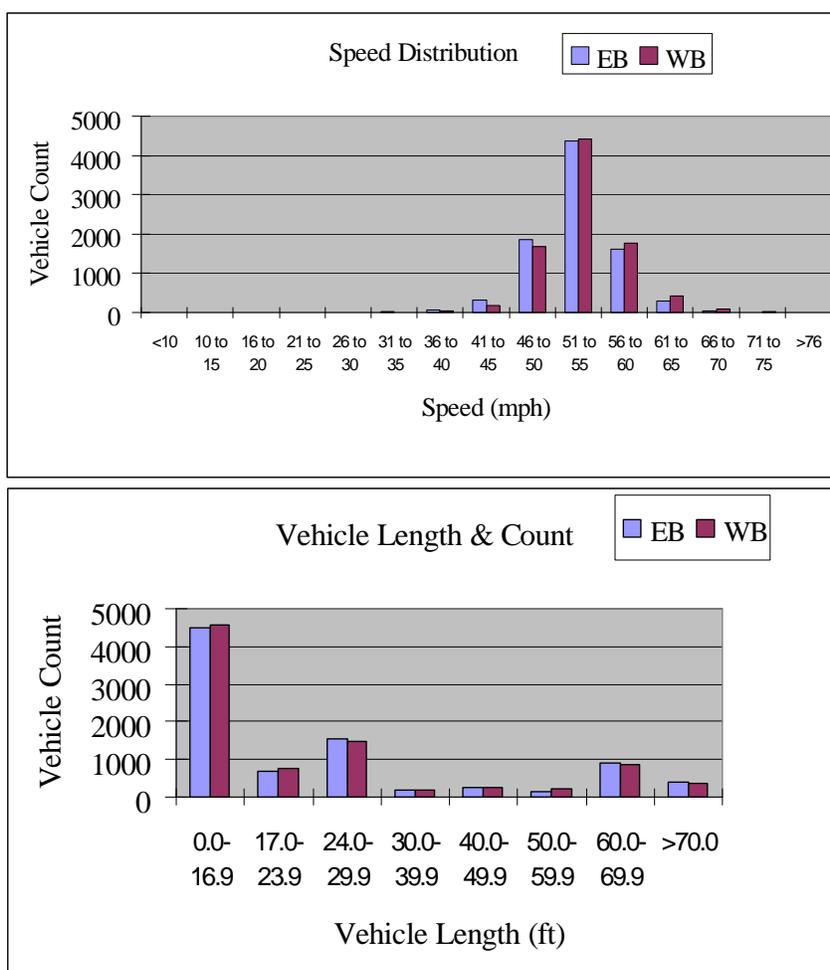


Figure 10 TransQ - Distribution of Vehicle Speed and Length in One Day

Table 5 TransQ - Vehicle Count with Percentage of Vehicle Traveling at Speed of 65 mph or Higher

Date	07-16	07-17	07-18	07-19	07-20
Vehicle Count	8610	8941	9844	8967	7814

Vehicle Counts of Speed > 65 mph	56	42	34	74	69
Percentage of Counts > 65 mph	0.65%	0.47%	0.35%	0.83%	0.88%

4.5 Summary of Data Analysis and Performance of Sensor Suite

Based on an overall review of data from various traffic monitoring systems, the following observations can be made:

- (1) The Caltrans Traffic Data Station is considered the most reliable data source because the station was validated during installation and the results across multiple data show consistent output. Given its combination of double loop construction, at least the vehicle count measurement should be fairly accurate.
- (2) The other surface-based sensing device, NC-200 (especially Position C), have vehicle counts most compatible with the Traffic Station, even though not every one of the three units provided credible results.
- (3) RWASS underestimates the count of passing vehicles, probably due to its relatively low mounting position at approximately one meter, which will cause some oncoming traffic obscured by leading vehicles.
- (4) Trans-Q has vehicle counts compatible with Traffic Station and NC-200, but it appears to have underestimated speed measurements.
- (5) Despite the differences in vehicle counts, several data sources provided very compatible estimates of speeder population in the range of 2-3 % on weekdays and 4-5% on weekends.
- (6) During the nighttime hours, the ratio of vehicles increased several folds to the range of 7-10 % on weekdays and 14-17% on weekends.

4.6 Technical Issues of ASE Sensing Devices

ASE has been widely adopted in many countries and regions around the world, yet the implementation of ASE in US has been relatively selective, especially on freeways or rural highways. There are many issues behind this phenomenon, yet one critical aspect has been the accuracy and consistency of speed measurements that need to be qualified enough to sustain the challenges in the court of laws.

A large number of ASE relies on the speed measurements by radar or laser devices. Radar is susceptible to more measurement noises and misidentification due to the natures of its operating principles. For example, one of the largest suppliers of red-light running and ASE equipment, Redflex⁷, has steered away from using radar and resort to using double measurements for their products. Redflex is the supplier that has successfully working with the state of Arizona on ASE projects on interstate highways near Phoenix.

From a technical point of view, the consistency or robustness of speed measurements for ASE can be improved by implementing redundancy, which can be pursued in several manners:

⁷ <http://www.redflex.com/>

- (1) Using alternate measurement devices that are based on different physical principles, such as a combination of
 - in-ground electrical loops and radar,
 - radar and laser
 - radar and consecutive photographs
 - laser and consecutive photographs
- (2) Using tracking radar
 - Conventional radar for ASE only captures and issues a triggering signal when the target vehicle passes its detection with one single instant of speed measurement.
 - Tracking radar captures the speed history of a target and records its trajectory data over a time window

5.0 CONCLUDING REMARKS

This paper describes a recent study that is designed to assess the technical performance of automated speed enforcement (ASE) equipment in the field. Several traffic monitoring systems were field tested with an automated speed enforcement system at a study site in California. The study site was located on a rural two-lane highway, where severe collisions occurred frequently and speeding appeared to be a significant factor. The ASE equipment and other devices were found to detect 2-5 % of passing vehicles to travel in excess of 65 mph in a highway with a posted speed limit of 55 mph. The percentage of speeders detected by several other traffic monitoring devices is in a compatible range, despite slight variations in their values.

Field experimentation is expected to resume for an alternate test site with multiple traffic lanes, which will provide a different setting for data collection and evaluation. Further analysis of collected data will also be conducted by examining records of individual vehicles. The assessment of technical performance of ASE and other traffic monitoring devices can provide insights in the process of validating functional characteristics and seeking performance enhancements. The outcome of this study, in conjunction with the experience and knowledge gained by other agencies in their development and implementation of work-zone and general ASE systems will offer valuable support for future ASE implementation.

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LIST OF FIGURES

- Figure 1 All Collision and Fatal Collisions along SR-12, 2002-2006
 Figure 2 Primary Collision Factors and Collision Types of SR-12, 2002-2006
 Figure 3 Vehicle Class and Speed Distribution in a One-Day Period on SR-12
 Figure 4 Devices Used in Data Collection for Technical Evaluation
 Figure 5 Layout of Equipment Setup at Data Collection Site
 Figure 6 RWASS - Speed of Passing Vehicles in One Day and Overall Distribution
 Figure 7 Caltrans - Speed of Passing Vehicles in One Day and Overall Distribution
 Figure 8 Caltrans - Length of Passing Vehicles in One Day and Overall Distribution
 Figure 9 NC200 - Distribution of Vehicle Speed and Length in One Day
 Figure 10 TransQ - Distribution of Vehicle Speed and Length in One Day

LIST OF TABLES

- Table 1 Performance Measures of Automated Speed Enforcement Equipment
 Table 2 RWASS Vehicle Count with Percentage of Vehicle Traveling at Speed of 65 mph or Higher
 Table 3 Caltrans Vehicle Count with Percentage of Vehicle Traveling at Speed of 65 mph or Higher

Table 4 NC200 – Position C - Vehicle Count with Percentage of Vehicle Traveling at Speed of 65 mph or Higher

Table 5 TransQ - Vehicle Count with Percentage of Vehicle Traveling at Speed of 65 mph or Higher