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16. Abstract

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Advanced Highway Maintenance and Construction Technology Research Center

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University of California at Davis

Final Report

Evaluation of Photo Speed Enforcement (PSE) in California Work Zones

Bahram Ravani: Principal Investigator,

Patricia Fyhrie, Chao Wang, Wil White, & Samuel E. Isaiah

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Division of Research, Innovation and System Information

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The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center within the Department of Mechanical and Aerospace Engineering at the University of California – Davis and the Division of Research, Innovation and System Information at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, State and Federal governments and universities.

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ABSTRACT

Exceeding the speed limit in highway work zones is a safety problem for highway workers and the traveling public. Adherence to the posted speed limits can provide safety benefits by reducing the number of accidents and the potential casualties and injuries resulting from those accidents. Some states have enacted laws and have adopted the use of automated Photo Speed Enforcement for highway work zones. This research was intended to evaluate existing practices and available technologies and perform testing to establish guidelines and recommendations for the equipment and the configuration for its deployment in California highway work zones. The main research question addressed in this research is the following: Can PSE technology be configured for implementation in highway work zones in California such that it be an effective deterrent to speeding, resulting in improving work zone safety for highway workers and the traveling public? In this research, testing was performed both in a controlled environment as well as in actual highway work zones. The performance of some of the existing PSE technologies, the parameters determining the effective utilization of this technology, and the magnitude of the speeding problem were evaluated. The results suggest that exceeding the speed limits is a major problem in California highway work zones and that using PSE is a viable option for improved work zone safety. Furthermore, important parameters for the effective utilization of PSE technology are identified, and a concept of operations for the potential deployment of this technology is recommended.

EXECUTIVE SUMMARY

Motivation

Work zone safety is important not only for highway workers but also for the traveling public. Adherence to speed limits in work zones can provide safety benefits by reducing the number and severity of collisions. Some states have enacted laws and have adopted the use of automated Photo Speed Enforcement (PSE) for highway work zones. The operational concepts and the technologies utilized are, however, different among some of the states utilizing PSE. This research was intended to evaluate existing practices, available technologies, and perform testing to establish the guidelines and recommendations of an operational concept for consideration in the deployment of such technology in California highway work zones.

Goals and Objectives

The overall goal was to evaluate available PSE technologies, the existing practices for its use, and whether the technology can be configured for implementation in California highway work zones in an effective manner that will result in adherence to the speed limits and improved work zone safety for highway workers and the traveling public. The particular research objectives were as follows:

1. Develop an understanding of the specific methodologies used by other states (for example, Illinois, Arizona, Oregon, and possibly Washington) and determine what lessons can be learned from these states' experiences.
2. Develop an understanding of the operational conditions that would limit the capability of existing PSE technologies.
3. Develop an understanding of some of the requirements for PSE technology in its effectiveness in the field.
4. Develop recommendations for operational concepts for an effective system of automated speed enforcement in highway work zones in California.

Research Methodology

A four-step methodology was used in this research. The first step involved bringing together, in a workshop, the key personnel involved in PSE implementation from some of the states in which it had been utilized. The workshop provided an opportunity to develop an understanding of the experiences gained by the participating states and their knowledge of what does and does not work in the process of instituting PSE. The second step involved testing PSE technologies in a controlled environment. A series of controlled tests were performed at CHP facilities. The tests were designed to determine the operational limitations of existing PSE technologies. The third step involved the field-testing of PSE technologies in active California work zones. Through coordination with Caltrans and the CHP, test sites were identified in both northern and southern California, and some of the available PSE technologies were tested in actual highway work zones. During the controlled as well as the field-testing, three different PSE technology vendors participated and provided their personnel and equipment for data collection. In the fourth and final step, results from the data collected during field-testing were analyzed to assess the magnitude of the speeding problem in California as well as to understand the limitations and capabilities of PSE technologies.

Results and Recommendation

The results from the field-testing indicated that exceeding the speed limits is a major problem in California highway work zones. For example, test results from the northern California test site (in the Stockton area) indicated that the number of speeding vehicles during the midnight to morning shift was in excess of approximately 500 to 1,000; in the morning and afternoon shifts, the number of speeding vehicles exceeded approximately 1,000 to 1,200. In southern California (in Los Angeles area), the corresponding numbers ranged from approximately 700 to 2,000 vehicles in the midnight shift, up to 2,000 vehicles in the afternoon shift, and up to 3,500 vehicles in the morning shift. Considering that the sensors were not able to capture all speeding vehicles in each lane or from multiple unobserved lanes, this data illustrates the numerical magnitude of the speeding problem in the work zones. There was no traffic count data available to evaluate the percentage of speeding vehicles compared with those driving within the speed limit during each shift.

The PSE systems tested did not generate an event for every detected vehicle at or above its trigger speed. If the quality of speed-reading was not good enough, the PSE systems did not take pictures of the vehicle, even if it was traveling at or above the trigger speed. However, approximately 60% of speeding vehicles for targeted lanes were captured by the PSE systems. For a fully citable event involving a speeding vehicle, both the license plate of the vehicle and the driver had to be properly identified. Some images were not very clear and some had obstructions due to the sun visor or drivers wearing sunglasses. Analysis of the data captured indicated that percentages of citable events were below 50% for all PSE equipment tested. At the test site in northern California, which evaluated two traffic lanes, the percentage of citable events was estimated at approximately 30-50%. In the data for the test site in southern California, which evaluated four traffic lanes, the percentage of citable events dropped to approximately 5-20%. The CHP, therefore, determined that while the PSE technology showed it had the ability to capture data, the reliability and the effectiveness of the findings did not meet the level considered necessary for its enforcement. It should also be noted that, although the percentage of citable events was relatively low, the number of events captured in any given period of time far exceeded the numbers that currently can be handled by on-duty police officers pursuing speeding drivers at the locations. For example, if one considers the morning shift, the number of potentially citable events for Stockton (the northern California test site) would range from 23-52 per hour. In Los Angeles (the southern California test site), similar numbers for the morning shift would have a range of 5-13 per hour. However, other issues were considered in CHP's determination not to implement PSE. These included, for example, problems associated with the judicial handling of citable events based on existing laws, the impact of the potentially much higher volume of citations on the judicial system, and the lack of any data on public acceptability of the use of PSE technology for work zone speed enforcement.

Based on the results of this research study, the recommendations are:

1. Any future implementation of PSE for work zones should start with a pilot study, with a clear review of its impact after the study.

2. Methods of communication with and notification of the public regarding the implementation of this method of speed enforcement need to be evaluated.

3. Any future implementation of this technology should include periodic reviews of its overall impact. For example, reviews can be conducted on a two-year basis and upon consideration of PSE's continued implementation based on the results of those reviews, especially in terms of its impact on improved safety.

4. Due to the potential sensitivity of the generated revenue, thoughtful governance on income dispersal brought in by fines should be addressed up front.

5. The relevant courts involved in the judicial handling of the citations generated need to be fully communicated with and provided the resources needed to manage the potential increase in the number of citations.

Special Note: The results of this research study have been shared with the California Highway Patrol (CHP). The CHP has made the following determination at this time: "while the technology showed photo speed enforcement images could be captured, the CHP does not consider the applicability of the photo speed technology as the only determining factor necessary for enforcement. Impact of photo speed enforcement on other stakeholders (e.g., Legislature, judicial council, and court systems) should be evaluated in developing a plan for future photo speed enforcement opportunities. The CHP requests to have an active role in any future photo speed enforcement opportunities."

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LIST OF ACRONYMS AND ABBREVIATIONS

ACS	Affiliated Computer Services
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
ATS	American Traffic Services
ATSC	Authorized Automated Traffic Safety Cameras
ASE	Automated Speed Enforcement
ASPE	Automated Speed Photo Enforcement
AUGSE	Augmented Speed Enforcement
Caltrans	California Department of Transportation
CHP	California Highway Patrol
CMS	Changeable Message Sign
COZEEP	Construction Zone Enhanced Enforcement Program
ConOps	Concept of Operation
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
GUI	Graphic User Interface
IT	Information Technology
LiDAR	Light Detection and Ranging
MSP	Maryland State Police
MUTCD	Manual on Uniform Traffic Control Devices
PSE	Photo Speed Enforcement
Radar	Radio Detection and Ranging
RFP	Request For Proposals
SR	State Route
SUV	Sports Utility Vehicle
TAG	Technical Advisory Group
WashDoT	Washington State Department of Transportation
WSP	Washington State Patrol

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INTRODUCTION

Background

Photo Speed Enforcement (PSE) involves using high-speed photography combined with a method of speed measurement to identify speeding vehicles and drivers. The two existing speed measurement systems used in PSE are based on Radar and LiDAR technologies. Both these technologies can provide accurate measurements of speed but require different equipment, calibration, and set up procedures. They are both commercially available as technology packages combined with high-speed photography for PSE applications. Photographic methods are used in California for certain traffic violations. Their uses in combination with speed measurement for speed enforcement in highway work zones have not been fully investigated. Several states enacted legislation to implement automated speed monitoring and enforcement in highway work zones. These states include Illinois, Oregon, Colorado, Arizona, Washington, and the District of Columbia. Prior to PSE's widespread implementation in California, however, the following research questions need to be addressed:

1. What are the most effective technologies or the most effective configurations of such technologies for automated speed enforcement in highway work zones?
2. What are the specific methodologies used by the very few other states (for example, Illinois, Arizona, Oregon, and Washington), and what are the lessons learned from the experiences of these states?
3. What kind of experience can be gained in terms of the requirements for and the effectiveness of such systems in the field?
4. What kind of recommendations can be made in terms of operational concepts for an effective system for speed enforcement in highway work zones?

Adherence to speed limits in work zones can provide safety benefits by reducing the number and severity of collisions and thereby reducing the number of casualties and injuries resulting from such collisions. Some states enacted laws and adopted the use of automated Photo Speed Enforcement for highway work zones. This research is intended to evaluate existing practices and available technologies, to perform testing to establish guidelines for its use, to provide recommendations for equipment, and to determine the appropriate configuration for its deployment in California highway work zones.

Automated Speed Enforcement in the U.S.

In 2009, the fatality and injury rates in highway work zones for a particular year in the United States were reported to be one every 13 hours and one every 13 minutes, respectively [1].

There is evidence that speed reduction on highways can improve highway safety in terms of reducing casualties (see, for example, [2-3]). The effectiveness of speed monitoring and enforcement on speed reduction has been shown in several studies (see, for example, [1, 4-5]). In addition, the long term effectiveness of speed monitoring was also evaluated in a pooled-fund study involving several Midwestern states (see [6]), where statistically significant improvements were found both in terms of speed reduction and increased compliance. The safety benefits of speed compliance in work zones are clear and substantiated by several studies. In the case of highway work zones, the California Department of Transportation (Caltrans) has partnered with the California Highway Patrol (CHP) and developed two programs: COZEEP (Construction Zone Enhanced Enforcement Program) and MAZEEP (Maintenance Zone Enhanced Enforcement Program). These programs provide traffic management strategies to improve project safety using supplemental CHP patrol units to assist in the enforcement of speed restriction and provide faster incident response to the selected work zones. However, these programs cannot be planned and implemented in all highway work zones. A challenge encountered by COZEEP and MAZEEP is that enforcement stops on highways can contribute to congestion as other drivers brake or slow to observe the situation, which can lead to additional safety issues. In addition, although the number of vehicle miles travelled in the United States increased, for example, by 26% from 1995 to 2007, the number of law enforcement officers grew by only 19% (see [7]) in the same period. This limited availability of resources is further exacerbated by other important law enforcement duties and new antiterrorism efforts. The development of other methods that can impact speed reduction in highway work zones therefore needs to be evaluated. Automated Speed Enforcement (ASE), Augmented Speed Enforcement (AUGSE), Automated Speed Photo Enforcement (ASPE), and Photo Speed Enforcement (PSE) are viable alternatives to the COZEEP and MAZEEP programs.

In the United States, automated photo enforcement has been used in many areas to improve traffic safety and to enforce traffic laws, including red light violations, the failure to pay tolls, making a right turn on red without stopping, passing a stopped school bus, and railroad crossing violations. The use of photo detection for speed enforcement is less common, however. A review and discussion of some of the barriers to its implementation are provided in [8].

The effects of PSE on speed enforcement in U.S. roadway work zones were first evaluated in Illinois [4]. Since these initial studies, several states have enacted legislation to implement automated speed monitoring and enforcement in highway work zones: Illinois, Oregon, Colorado, Arizona, Washington, and the District of Columbia.

Arizona had a PSE program for highways from 2008 to 2012. Due to the fatal shooting of a PSE operator working on equipment alongside the highway, its use in Arizona became controversial, and the program was cancelled in 2012. Before the program cancellation, Northern Arizona University performed one of the initial studies for PSE implementation in Arizona [9]. Other studies evaluated the before and after effects on “Loop 101” in the Scottsdale area [10-11].

These studies indicated that PSE programs were successful in reducing the speed of motorists. Further studies related to the Arizona program provide useful data, including "lessons learned" (see, for example, [12-13]).

The Illinois law enacted in 2004 required PSE use in highway work zones only when workers were present. It also required that photo enforcement warning signs be placed before the enforcement site. The PSE program implemented used two radar systems: one down-the-road and one across-the-road. The speed-reading from the down-the-road radar was only for warning purposes and was displayed on a video board. Its display was intended to give the driver one more chance to correct the speed of his or her vehicle. The across-the-road radar measured the speed of each vehicle when 150 feet upstream of the PSE system. It triggered two onboard cameras for photographic documentation, and its data was used for ticketing and enforcement.

The Oregon law enacted in 2007 was very similar to that of Illinois [14-15]. When using PSE in Oregon, at least one worker has to be present at the work zone for a citation to be issued. A police officer in a marked vehicle has to be present, as well. The Oregon law also requires (as in Illinois) that the violating vehicles' speed be displayed for the driver to see within 150 feet of the photo radar unit.

Initiated in 2007, the photo speed enforcement used in Washington is known as Authorized Automated Traffic Safety Cameras (ATSC). The operator of the PSE unit (a sworn highway patrol officer or the PSE Technology Package employee) verifies the violation captured by the system. The license plate information is then sent to Department of Licensing National Data Base. After receiving the information, the operator compares the vehicle's information to the license plate. He or she then sends the information to the Washington State Patrol (WSP) to be verified. When approved by WSP, the information is electronically sent back to the PSE Technology Package vendor for mailing. The operator issues the infraction to the registered owner and the applicable district court for processing.

Washington State Department of Transportation (WSDOT), together with Washington State Patrol (WSP), performed pilot testing of automated speed enforcement in work zones starting in 2008. In their pilot study, they reported issuing approximately 1,300 infractions during a five-week period and observed a drop in the number of cars speeding in the enforcement area of the work zone. The traffic incidents in the test areas were reduced to zero that year because 90% of drivers dropped their speed to slower than 70 MPH when they realized that PSE was in use. In 2009, more than 1,900 infractions were issued in the construction zone test areas on Interstate 5 Freeway (I-5) south of the city of Olympia alone [16]. The Washington State Patrol initiated a campaign called "Give 'em a Brake" along with the PSE program. The "Give 'em a Brake" campaign contained tips on how to watch out for workers and focused on the safety of drivers and workers in construction zones.

The PSE program implemented in Washington includes the following regulations for issuing citations to speeders:

- Identification of the rear license plate must be sufficient.
- Warning signs must be positioned 150 feet upstream of the PSE location to notify drivers of the PSE enforcement zone.

Photographic documentation of the driver's face is not required. Rental car businesses are relieved of responsibility for the citations if they provide the State Patrol the name of the driver or declare that they are unable to determine the driver or the renter of the vehicle. Infractions do not appear on the registered owner's driving record.

In the state of Maryland, Transportation article 21-810 of the state's annotated code authorized the use of the ASE or PSE program in work zones in October 2009 [17]. The use of ASE or PSE program was implemented as follows:

- Speed cameras may be placed along expressways and controlled access roadways with at least a 45 MPH speed limit.
- Citations may be issued when drivers are exceeding the speed limit by 12 MPH.
- Drivers should be provided adequate notice of the cameras by posting conspicuous signs.
- There should be a 30-day warning period upon the implementation of the program in any specific area.
- There will be no points against the speed violators cited.
- The district court set the amount of the civil fine at $40.
- Revenues generated by the PSE or ASE program first cover administering Maryland's safe zones programs, with any excess going to state police roadside enforcement activities.

The PSE system in Maryland uses Light Detection and Ranging (LiDAR) laser technology rather than Radio Detection and Ranging (RADAR). The LiDAR system is operated by a trained individual who performs a set of calibration tests prior to its application. Maryland State Police (MSP) review the violations identified by the operator to monitor the accuracy and issue the violations. More information on the PSE program in Maryland can be found in [17-18].

In the state of Colorado, PSE has been allowed in work zones since 2009 [19]. The use of PSE to further improve work zone safety in Colorado was found to be effective and accepted by the public [20-21].

The current state of PSE technology, including a list of some of the available vendors for its deployment, is addressed in [22]. A discussion of the legal environment considerations when using PSE can be found in [23]. A brief summary of PSE implementation in selected states is provided in Table 1.

Overview of Research Results

Analysis of the data obtained in this research clearly indicates that speeding is a major issue in California highway work zones. Furthermore, data from the field-testing performed in this research at active work zones shows the viability of using photo speed enforcement to improve work zone safety by reducing the speed of the traveling public. In addition to field-testing, this research has also performed controlled testing to identify the key parameters that influence the effective utilization of photo speed enforcement in highway work zones. Using the analysis of the data obtained in this research, a concept of operations has been developed for consideration for the potential deployment of the PSE technology to improve the safety of highway workers and the traveling public in California highway work zones. Furthermore, any such consideration is to be coordinated with CHP to make sure that other factors such as the impact to the work load of the judicial system or procedures for judicial handling of the resulting citations are fully accounted for. This research has also evaluated some of the commercially available PSE technologies and has determined that commercial systems are available that can be easily deployed for implementation of the technology in work zones.

- **Arizona** – statewide application. (The statute establishing funding for Arizona's PSE program was repealed in July 2012.)
- **California** – no state law, but the program is operating on mountains, recreation, and conservation authority park roads.
- **Colorado** – restricted to construction and school zones, residential areas, or areas adjacent to a municipal parks.
- **District of Columbia** – jurisdiction-wide authority to use automated enforcement to capture all moving infractions.
- **Illinois** – statewide use only in construction zones or Illinois Toll Authority roads; local authorities are prohibited from using speed cameras; state may use speed cameras, but only when a law enforcement officer is present and witnesses the event.
- **Iowa** – no state law, but programs are operating under local ordinance.
- **Louisiana** – state law provides that convictions resulting from camera enforcement shall not be reported for inclusion in the driver's record; the law is silent on other issues.
- **Maryland** – Montgomery County school zones and residential districts; Prince George's County school zones; statewide in school zones by local ordinance and work zones.
- **Missouri** – no state law, but programs are operating under Missouri DOT policy.
- **Ohio** – no state law, but programs are operating under local ordinance.
- **Oregon** – specific cities where PSE is permitted; may not be used for more than four hours per day in any location.
- **Tennessee** – statewide, except for interstate highways that are not work zones.
- **Utah** – statewide only in school zones or where the speed limit is 30 mph or less; officer must be present; requires local ordinance.
- **Washington** – applicable in school zones only. (A recent budget bill authorizes pilot programs overseen by the Washington Traffic Safety Commission to detect speed violations within cities west of the Cascade Mountains that have a population over 195,000. A pilot project to test PSE in work zones continues under the new budget.)

Table 1. Summary of PSE Use in Selected States.

RESEARCH APPROACH

Introduction

The approach taken in this research involved using a Technical Advisory Group (TAG) combined with a four-step methodology. The TAG consisted of key personnel from Caltrans and CHP and guided all aspects of this research. Following is the four-step methodology used in this research:

1. Evaluated the work of other states to learn from their experiences
2. Tested in a controlled environment to determine the capabilities of existing technologies and develop a concept of operations for testing in active work zones
3. Tested in active highway work zones to develop data for designing a concept of operations
4. Analyzed the data obtained from the two series of tests and synthesized the results with experiences gained from the work of other states to design and recommend a concept of operations for California

In order to perform the first step, the existing literature was reviewed and a two-day workshop was organized in San Diego, California. Key personnel involved in PSE implementation from some of the key states were invited. The workshop provided a working environment to develop an understanding of the experiences gained by the participating states and discover what did and did not work. The controlled environment testing was performed by CHP personnel at CHP facilities. The actual test scenarios used in the controlled testing were designed by the AHMCT researchers. Different PSE technology vendors were invited to participate and to test their technologies. The test data was used to assess the capabilities and the effectiveness of some of the available technologies and to develop a preliminary concept of operations for PSE implementation and testing in active highway work zones.

Through coordination with Caltrans and the CHP, test sites were identified in both northern and southern California. PSE technologies from the same vendors who participated in the controlled testing were tested in active highway work zones. The results were analyzed to assess the magnitude of the speeding problem in California and to develop a concept of operations that could be considered for implementation if laws are enacted that would allow PSE use in California highway work zones.

The results of the work performed in step one of the methodology, are described in the remainder of this chapter; the results of the other three steps are described in subsequent chapters.

Workshop with Other States

In order to learn from the experiences of other states in the use of PSE systems, technical experts from Illinois, Washington, Oregon, Pennsylvania, Colorado, and Arizona attended a workshop to share their knowledge with the research team. At the workshop, each state gave a presentation, which was followed by dialogue and roundtable discussions. The workshop took place in San Diego on February 27, 2013 to take advantage of the attendees' presence at the AASHTO conference preceding the workshop.

Each expert described how their PSE system operated in his or her state. Additional resources were shared with the group, providing further detail about legislative activities, performance specifications, and background. A group discussion was also conducted to give all representatives an opportunity to clarify topics and expand upon their earlier statements. The following list sums up these discussions and presentations and synthesizes the workshop's main points:

1. Identification of the Speeding Vehicle and Driver
    a. All states implemented service contracts making the vendor responsible for the technology.
    b. Vendors had the incentive to improve equipment capabilities. This increased the number of successfully adjudicated tickets, which increased income.
    c. Radar was used in all mobile systems described.
    d. Some vendors recommended LiDAR, but it is not certified by International Association of Chiefs of Police (IACP).
    e. Cosine and road curvature effects are known issues for radar accuracy in identifying speed of vehicles. Officers are trained to deal with these issues when sites are set up.
    f. Location of equipment on the CHP vehicle must be considered. Radar must see over protective barriers. Interior room for the officer and the hardware must be sufficient for the officer and his or her standard gear. Safety of the personnel must be considered.
    g. Nighttime operation of systems is effective.
    h. Glare to driver from flash can be reduced and/or filtered.
    i. Daytime use can be problematic because the sun glare off windshields can affect photos.
    j. Multiple-lane operation is an issue when there are three lanes or more. Need to understand and test vendor claims on their system capability to capture speeding vehicles in all lanes.

2. Identification of Errant Driver
    a. Photos of driver are used when required. Arizona system used very high-resolution black and white photos.
    b. Only Arizona used video, which provided valuable supporting evidence.
    c. The driver was not notified of the infraction at the site where the violation was captured. Notification was mailed to the vehicle registrant after verification of the event.
    d. Officers are involved directly or indirectly at various stages in the ticketing process. Arizona deputized employees working for the vendor.

3. Ticketing Process
    a. Process for ticketing is complicated and varies between states.
    b. Vendor is usually integrated into the process.
        i. Example: The vendor collects the data, reviews it for quality, and provides it to police. Police look through data and verify viable tickets. The verified data is returned to the vendor to issue tickets, process notifications, etc. In some cases, the vendor provides support in court.
    c. Vendor has incentive and is responsible for quality of evidence.
    d. None of the process is done in real time. All processing is done at the office.
    e. Arizona's unstaffed systems used video as supporting evidence.
    f. There may be legal issues associated with photos that can be used as evidence in other cases.
    g. Vendors may have costs accessing necessary data such as registration information.
    h. The speed at which a ticket should be issued is debatable. One question that arises is that what should be the speed margin for issuing a ticket?

4. Integration of Law Enforcement
    a. Need to consider accuracy of speed detection equipment.
    b. Keep consistent with current ticketing protocols.
    c. Relationship of speeds to tickets may or may not reflect "reckless" driving levels.
    d. Arizona issued tickets when speed exceeded 11 mph over the speed limit. In other states Police typically determined the allowed speed margins.
    e. Illinois made speed violations identified by PSE in work zones to be moving violation.
    f. Police determine speed margins.

5. Police Visibility
    a. Van/SUV containing equipment is clearly marked as police.

   b. Some states also used additional police units for enforcement purposes… not just to issue tickets; these are also kept visible.
   c. If work zone is "long," the police unit may be parked downstream.
   d. Placement of PSE vehicles was determined on a case-by-case basis.
   e. Placement locations were determined by local personnel; the safety of police workers and equipment were high-priority factors in determining placement.
   f. Illinois required the presence of a police officer in the van.
   g. Other states use the vendor in the van to operate the equipment; officer then reviews afterward in the office and determines which tickets are "valid."

6. Deployment of Equipment
   a. Illinois, Arizona, and Oregon let vendor place the equipment where needed.
   b. All equipment is mounted in a clearly marked police van or SUV and deployed on site.
   c. In some cases, the vendor placed signage and ran equipment.
   d. Vendor should be part of the local decision-making process to help determine placement of safety equipment, work zone barrier, signage, van placement, etc.
   e. Some collisions with equipment occurred. Arizona had a shooting incident.

7. Lessons Learned
   a. When the program was shut down in Arizona, many non-adjudicated citations required continued funding in order to be processed.
   b. There must be a consistent message of "Voluntary Compliance."
   c. All groups participating must provide a consistent message regarding the purpose of PSE and how it is implemented.
   d. Many people/groups are involved. It's important to keep all on board and in the decision-making loop.
   e. Processing is complicated when out-of-state drivers and vehicles are involved.
   f. Legislation should not engineer the system.
   g. Constantly communicate with the vendor and KNOW YOUR CONTRACT. Hold the vendor to it.
   h. Consider completing a traffic study to support justification.
   i. Get the agencies' Information Technology (IT) involved in early phases of implementation. For example, Iowa DOT owns the data. It must be compatible with all systems, including the court.
   j. Don't let the RFP exclude or narrow post-contract monitoring.

8. Greatest Challenges
   a. Fiscal viability over a period of time.

   b. Significant lead time to get program up and running, get approvals at all levels, initializing the "system." All takes time.
   c. If contract is "too short" in duration, then the trial period could be over before it is started.
   d. Legislation - You will have to live with what you get. Get it right the first time. Labor intensive in the beginning. Also be certain there is sufficient detail in the legislation.
   e. Getting courts on board initially led to them being fully supportive later on.
   f. The Texas DOT tried to evaluate PSE and ran into a political conflict. The early research was shut down and the legislature enacted a law that prohibits TXDOT from evaluating any PSE technology.
   g. Recommend tests of the technology first, then move to legislation, and finally to implementation.

9. Revenue Stream
   a. If many tickets are generated using PSE, how does the cost to adjudicate affect the courts?
   b. How many tickets are paid?
   c. Does the vendor get paid? Per valid ticket independent of resultant ruling?
   d. What to charge for the ticket to cover additional costs?

Summary of Concept of Operations from Other States

Each state employing Photo Speed Enforcement must develop its own protocol in which to operate the PSE system. The established protocol must be consistent with each state's laws and regulations. Using PSE in highway work zones should be distinguished from using PSE in school zones and other fixed locations. In this research, the former is referred to as mobile application of PSE since the location of PSE equipment can be moved as the work zone moves. The use of PSE in a fixed location such as a school zone is here referred to as a stationary PSE configuration. It should be noted that stationary speed enforcement has different performance specifications than mobile PSE systems. Consequently, the methods described below will be applicable only to the mobile PSE systems. The following list summarizes the methods developed by other states and offers possible strategies that California can use if PSE is implemented.

1. Equipment
   a. A third-party vendor is selected to provide the needed hardware system such as sensors, specialized cameras, strobe lights, electronics, and computers.
   b. Known vendors in current use include: Affiliated Computer Services (ACS), American Traffic Services (ATS), Redflex, and Xerox.

c. Currently, Across-the-Road Radar Modules are predominantly used, although LiDAR systems are available.
d. A dedicated vehicle (van or SUV) is retrofitted to transport and support the PSE hardware and operation when on the road. The vehicle is mobile and can move from site to site. Set-up time and calibration is necessary at each destination.
e. PSE Vehicles are clearly identified as such when in operation.

2. Signage
   a. Each state develops signage specifications to be consistent with both federal and state laws designated in the Manual on Uniform Traffic Control Devices (MUTCD).
   b. In general, visibility and conspicuity of signage is prominent.

3. Operation
   a. Each state worked with their selected vendor to determine operation protocols.
   b. Operation protocols are determined by corresponding legislation. A range of procedures from the complete delegation of operation to the vendor to the state police performing all of the operations were used.
   c. The most common speed threshold was 11 mph over the speed limit.
   d. Operation protocols were dependent on whether the state requires a photo of the license plate or requires identification of both the license plate and the driver.

4. Ticketing
   a. Post-processing of each "event" generates the ticket.
   b. Tickets are classified in both moving and non-moving violations. All have associated fines from approximately $100 to $500 (first-time violation).

All tickets are given to the vendor for post-processing with the option of police "double-checking" citations.

Summary of Experiences from Other States

1. Legislation
   a. States currently use a radar module to detect speeding vehicles because radar equipment can be legally certified. Consequently, if the ticket is contested in court, the speed value is difficult to deny.
   b. Due to the sensitivity of the generated revenue, thoughtful governance on income dispersal brought in by the fines must be addressed up front.

c. Prior to implementing the PSE system, consideration should be evaluated on the potential of an exponential increase in citations issued and the resulting increase in court activity. The courts need to be fully advised and provided the extra resources needed for the increased number of contested tickets.

2. Communications
    a. Strong communication efforts to educate both the police and the public were found to have an effective influence on the success of the PSE program. Program acceptance by the public and Police agencies usually took between 1 to 2 years.
    b. States found it critical to communicate to the public that the PSE system is used to increase safety and NOT used as a revenue generator.
    c. With respect to Enhanced Enforcement Programs, it is indicated that demand for police presence in the work zones exceeds the available resources. It is hoped that the use of PSE will be able to supplement police enforcement, not replace it.

CONTROLLED TESTING

Background and Rationale for Controlled Testing

The controlled testing was performed at the CHP Academy in West Sacramento, California on August 1st, 2013. It consisted of a series of six tests performed in one day utilizing different types of vehicles driven by CHP officers on a test track facility. Different PSE equipment positioned alongside the test track were used to detect the vehicles, identify their speeds, and capture the license plates and visual images of the drivers. The purpose was to evaluate the effectiveness of some of the available PSE technologies in determining and developing methods of speed reduction in California highway work zones. A total of 75 tests were conducted as part of this evaluation. The following set of **minimum data** on effectiveness of PSE equipment was obtained from each of the participating vendors for each of these tests:

a. Determination of vehicle speed.
b. Identification of the vehicle (for example, its license plate number).
c. Capturing a clear picture of the driver.

The testing was performed in one day with three test sessions: one in the morning, one in the afternoon, and one in the evening, with breaks in between.

Several vendors were invited and three participated in the testing. The rationale for the testing was fourfold: 1) To evaluate some of the capabilities of PSE systems to measure the speed of the vehicles; 2) To assess the capability of PSE systems in capturing speed and key data of vehicles in different lanes; 3) To evaluate the quality of images in identifying license plate numbers and drivers' faces; 4) To determine the effects of sun glare, night time lighting, and shadowing (which occurs when vehicles are moving in adjacent lanes and can partially block key information from the direct line of sight of the PSE system) on the PSE systems' ability to capture the essential data.

The controlled testing was designed to assess some of the parameters that can help in developing system and operational specifications or the concept of operations for the potential use of PSE in California highway work zones. It is presumed that PSE speed enforcement in California will require the presence of a CHP officer at the scene along with a clear, unobstructed photograph of the driver in violation, the license plate, and the vehicle. The required PSE system specifications can be summarized as follows:

a. **Vehicle speed measurement:** The accuracy of processing the maximum speed of the speeding vehicle and the method of identifying the vehicle from a group of vehicles in different lanes is paramount.

b. **Driver identification:** The ability to verify the identity of the driver by comparing the PSE photograph with archived photographs in the Department of Motor Vehicles (DMV) database is essential. Photograph clarity, required illumination, and robustness with respect to low light and glare must be maintained.

c. **Vehicle identification:** The ability to authenticate a photographic depiction of the license plate of the vehicle with enough clarity to identify the plate number is required.

d. **Range of operation:** The maximum number of lanes that can be effectively monitored by the system must be determined.

e. **Longitudinal requirement:** The established length of straight road required for proper operation of the system is required, which determines the placement limitations of the PSE unit.

f. **Communication requirements:** The methods that the system uses to provide information on violators to CHP must be stipulated.

g. **Packaging requirements:** Any system components and installation requirements that can impact the system's mobility, power requirements, and space needs at a site must be prevented.

h. **Set up and take down requirements:** Any constraints that impact the mobility and exposure at a site must be prevented.

i. **Staffing requirements:** Any impact on personnel requirements at the site or "behind the scenes" must be prevented.

j. **Data storage and transfer requirements:** The manner and length of time data is stored and the method of data transfer from the site to the ticket issuing office.

Test Facility

The test facility selected was the test and training track at the CHP Academy in West Sacramento, California. This is depicted in Figure 1. The track has an asphalt roadway including a long straight stretch where vehicles can be accelerated to highway speeds with enough distance to maintain their speed before going around or cutting the loop and returning to their starting positions. The straight section is shown in Figure 2; the locations of PSE cameras used in testing are also shown.

Figure 1. Test Track Facility at the West Sacramento CHP Academy.

Figure 2. Straight Section of the Track Looking in the Direction of Oncoming Traffic.

The straight section was in the northeast corner of the track and the PSE equipment was positioned approximately 200 feet apart, as shown in Figure 3.

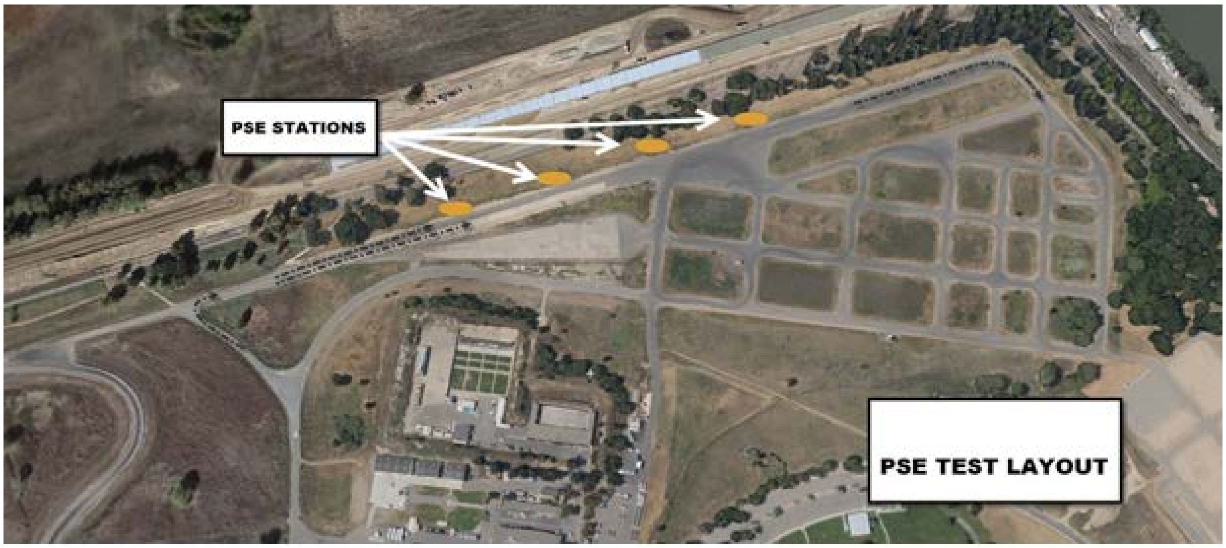

Figure 3. The Positions of the PSE Stations in the Straight Section of the Test Track.

Test Plan

A series of six tests were planned to assess accuracy of speed measurements in single as well as multiple lanes and to evaluate the effects of shadowing in detecting speed violators. These tests also included testing to evaluate the effects of sun glare and nighttime illuminations in driver and license plate identification. The methodology involved positioning PSE technology vendors participating in the study approximately 200 feet from one another while CHP officers were performing the testing by driving vehicles in tandem and in juxtaposition to other vehicles. These conditions were repeated against the sun to evaluate the effect of sun glare. Tests were also repeated in the evening to evaluate the effect of work zone illumination lighting. All the tests were conducted in the same day in three sessions, with breaks in between. The morning session testing measured vehicle speed in single versus multiple lanes and evaluated the effects of shadowing on the image quality. The afternoon session testing evaluated the effects of sun glare on the image quality. The evening session testing evaluated the effects of highway work zone overhead lights on the image quality.

Test Descriptions

The controlled testing performed consisted of a set of six tests under four major categories: speed measurements in single and multiple lanes, shadowing tests, sun glare tests, and nighttime tests. Each of these categories is described below.

Speed Measurements in Single and Multiple Lanes

Two series of tests were performed in this test category. These test series constituted test set one (single-lane testing) and test set two (multiple-lane testing), all performed in the morning session.

The first test series was intended to determine the ability of the PSE systems to capture vehicle speed in a single lane. Three sedan-type vehicles driven by CHP officers traveled in tandem approximately two seconds apart at three different pre-set speeds of 50 MPH, 60 MPH and 70 MPH. The tests were repeated for lanes one (1), two (2), and three (3), while the PSE equipment from the three participating vendors was in fixed locations in the shoulder, placed approximately 200 feet from one another. This series of tests is illustrated in Figure 4 below. In this figure, the positions of the PSE equipment are indicated as PSE Technology Packages.

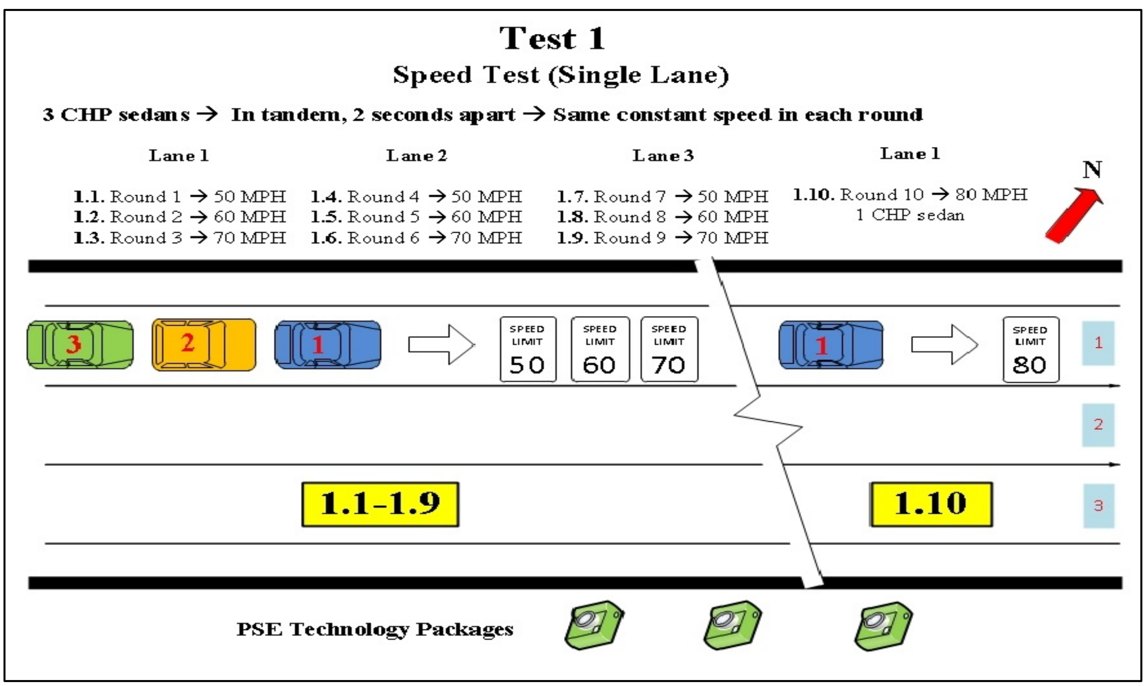

Figure 4. Single Lane Speed Detection Test Series.

The second test series in this category involved speed determination for vehicles in adjacent lanes. It consisted of the following tests, as illustrated in Figure 5 which depicts the following test scenarios:

a. Two sedans traveling at 60 MPH adjacent to each other in lanes one and two.
b. One sedan and a motorcycle traveling at 60 MPH adjacent to each other in lanes one and two.
c. One motorcycle traveling at 60 MPH in lane one.

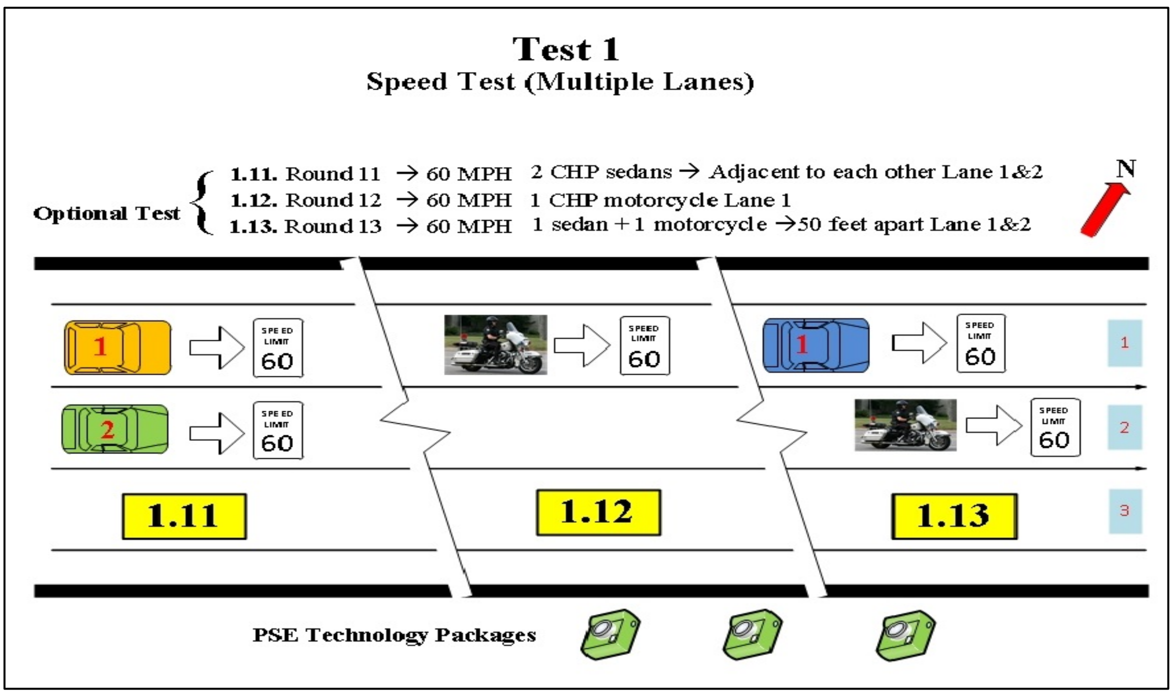

Figure 5. Speed Determination Tests for Vehicles in Adjacent Lanes.

Shadowing Tests

Shadowing refers to the situation when a speeding vehicle is in the cameras' blind spot at the time of the speed detection. Two test sets were performed in this category, as depicted in Figure 6. The first set consisted of a series of tests performed separately at the position of each

PSE package. It involved having two sedan vehicles in the number one and number two lanes, with the vehicle in the number two lane going at a speed below the trigger speed for the PSE detection and positioned such that it would the block proper view of the speeding vehicle in lane one. The speed for the speeding vehicle was chosen to be 55 MPH, and the other vehicle was traveling at 45 MPH. This test series is depicted in the left side of Figure 6. This test had to be performed several times at the location of each vendor's PSE equipment to make sure that the relative positions of the two vehicles would produce the shadowing effect.

In the next test set in this category, a bus was parked approximately 30 feet and then 60 feet from the location of PSE equipment, as shown in the right hand side of Figure 6. The test vehicle, a sedan, would travel in lane number one at 60 MPH. The test was repeated for each PSE equipment location.

Sun Glare Test

This test set evaluated the performance of PSE equipment in the presence of sun glare. It was performed in the afternoon when the position of the sun was such that windshield glare would be an issue. Two series of tests were performed in this test set. The first series is depicted in the left-hand side of Figure 7 and consisted of four rounds of tests. In rounds one and two, two sedan-type vehicles were driven in tandem at two seconds apart. The vehicle in lane one traveled at 55 MPH and other traveled at 65 MPH, respectively. In rounds three and four, the same process was repeated in lane number three.

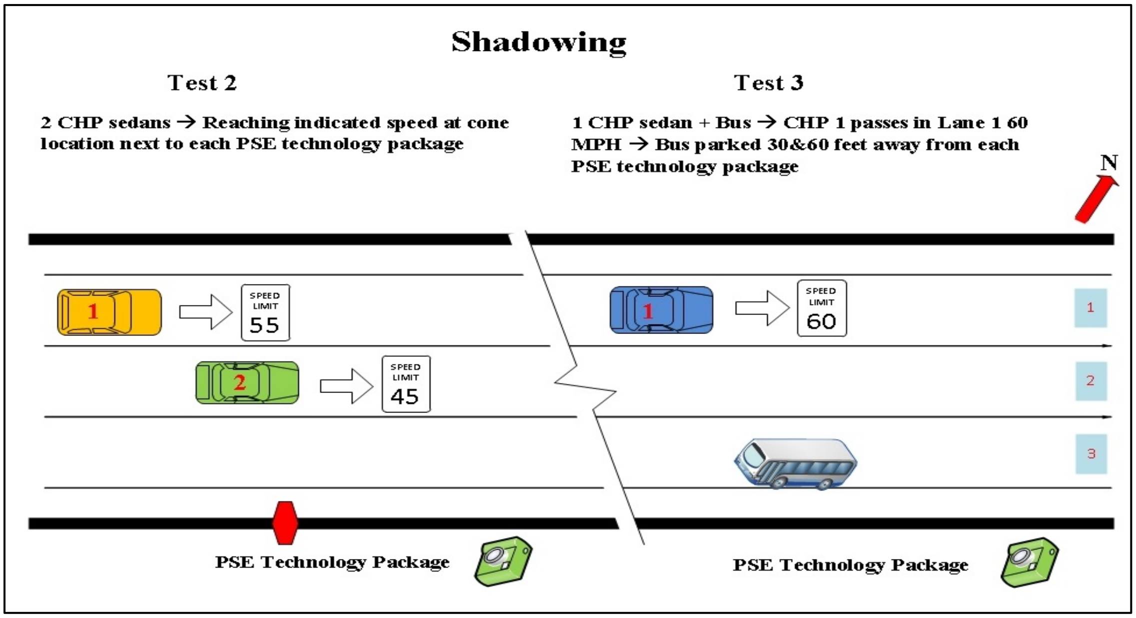

Figure 6. The Two Test Sets for the Evaluation of Shadowing.

The second test series in this set involved repeating the same number and type of tests of the first test series but having the vehicles run in the opposite direction, as depicted in the right-hand side of Figure 7.

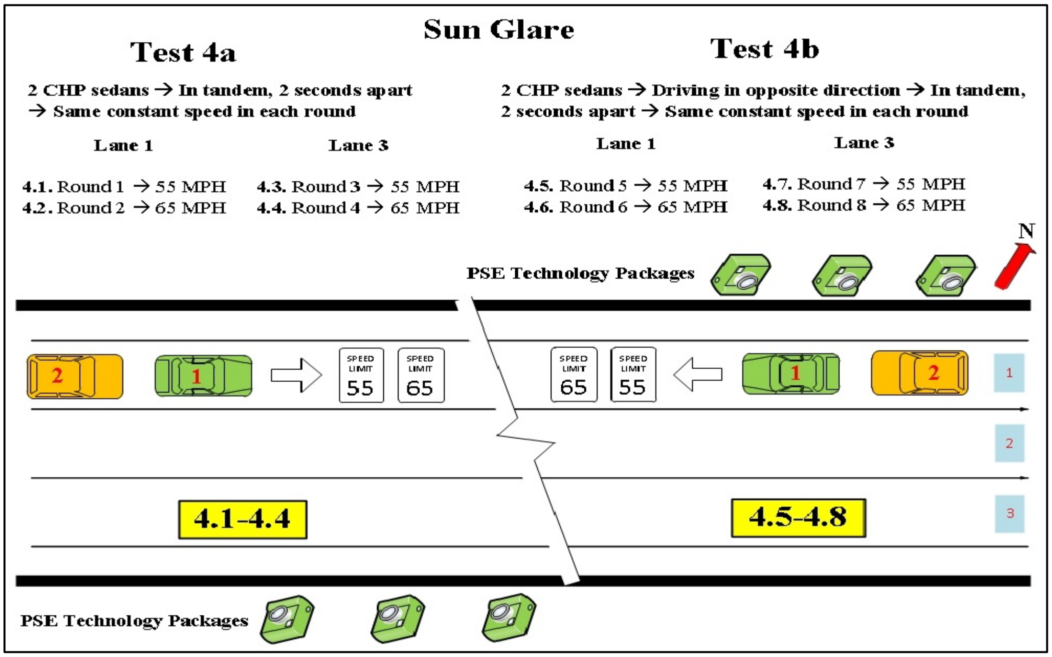

Figure 7. Two Test Series Evaluating Sun Glare Effects.

Nighttime Testing

This test set consisted of two series of tests starting at 8:00 p.m. and ending at 10:00 p.m. The first test series in this category of tests consisted of three rounds of tests all involving two sedan-type vehicles traveling in tandem in adjacent lanes approximately 100 feet apart at 60 MPH, as shown in Figure 8 . The location of the overhead work zone style lighting was changed in each round, as depicted in Figure 9.

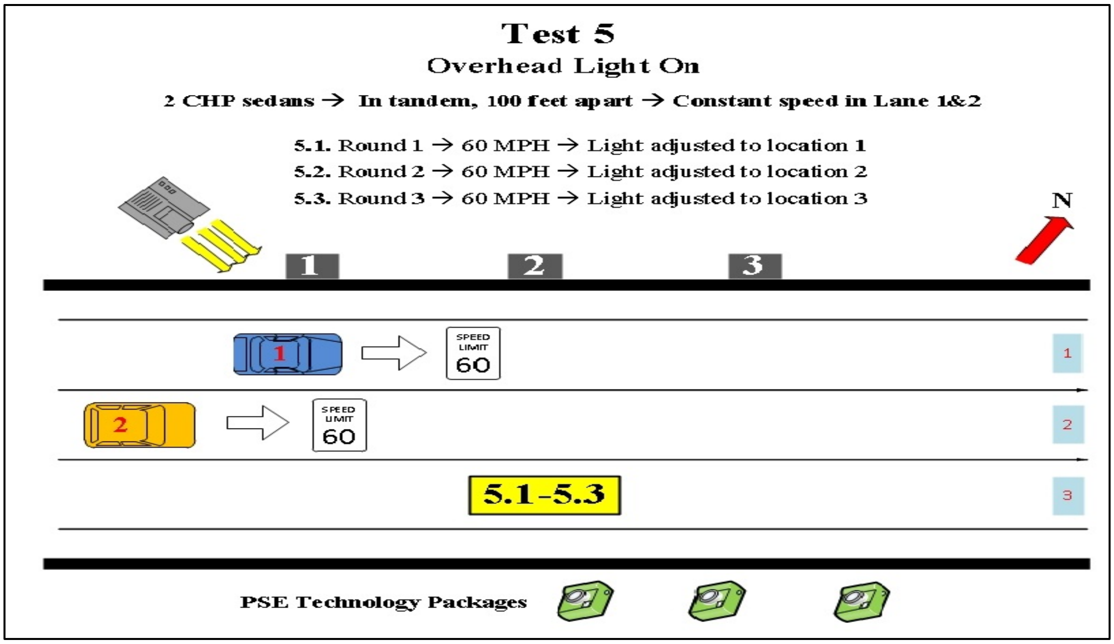

Figure 8. Night Testing with Overhead Lights Simulating Work Zone Lighting.

The second test series in this category consisted of one round of tests with the same condition as the first test series in this category except there was no overhead lighting, as depicted in Figure 9.

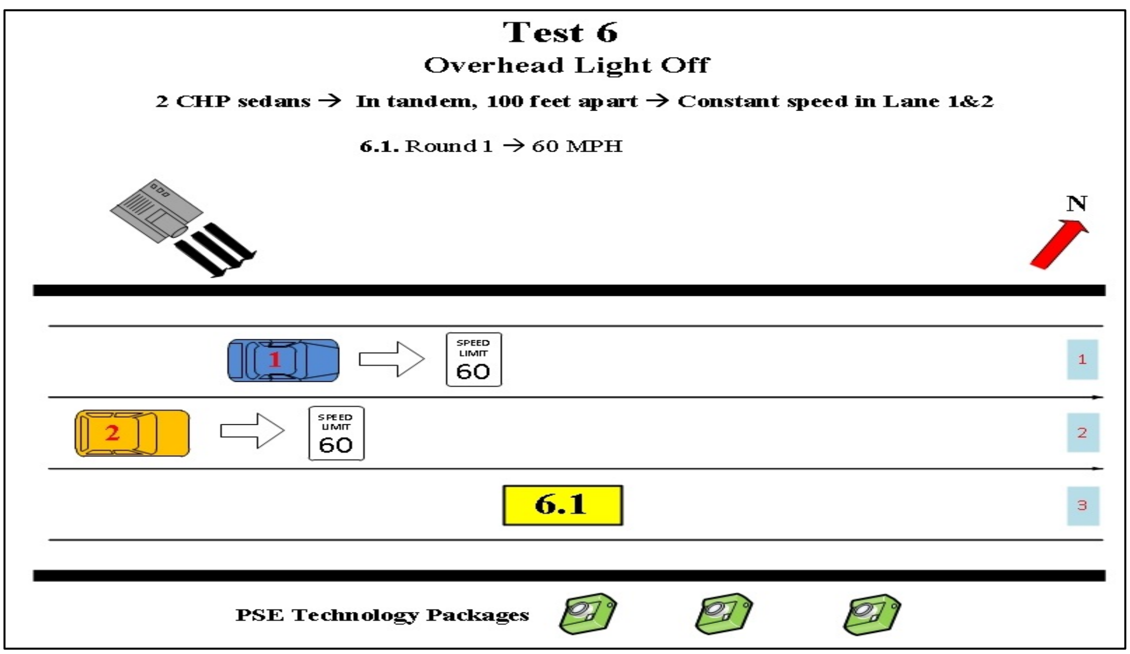

Figure 9. Nighttime Testing with No Overhead Lighting.

Test Data and Analysis

The data captured in the controlled testing was analyzed to determine identification of the driver and the vehicle. For each test, at least three images were obtained from each of the three vendors' PSE equipment. These consisted of images of the driver's face, the front license plate, and the rear license plate. A scoring system was developed to rate the clarity of the facial images and the license plate numbers. For facial images, the scoring system was from 0 to 3, with 0 corresponding to images where the face was not identifiable and 3 corresponding to images where the facial features were clear and face was highly identifiable. The same scoring system was also used for license plate identification; a score of 0 or 1 indicated that at least one letter or digit in the license plate was not identifiable, and 3 indicated all letters and digits were clear and identifiable The scoring system for facial identification also included scores of 2.5, since it was very difficult to rank some of the photos between the scale of 2 and 3. The addition of a score of 2.5 in the rating scale for the images that fall between the ratings of 2 and 3 allowed a more accurate evaluation of the facial images. All the images which were rated 2 or 3 had recognizable images of either the driver's face that could be used to match with the driver's license photo or a clear image identifying the front or back license plate number of the vehicle. A flow chart was developed, as depicted in Figure 10, to assess if captured images represented a citable event.

In evaluating all images, four different researchers independently applied scores to them. In order to reduce variability of scoring between the researchers, five image sets were selected as templates for which all four researchers' scores agreed for ratings of 3, 2.5, 2, 1, and 0. These templates were used as baselines by each of the four researchers as they processed the other images.

Each vendor's PSE equipment missed capturing data for some of the tests performed due to some technical difficulties. The percentage of the events captured by each vendor is depicted in Figure 11 below. In this figure, each vendor's PSE equipment is represented by a different color. In comparing the quality of the images captured, the missing data in the data set were not included. This is because different vendors, given sufficient preparation time, may have been able to work out the problems they were encountering in not capturing such events had there not been the tight testing schedule.

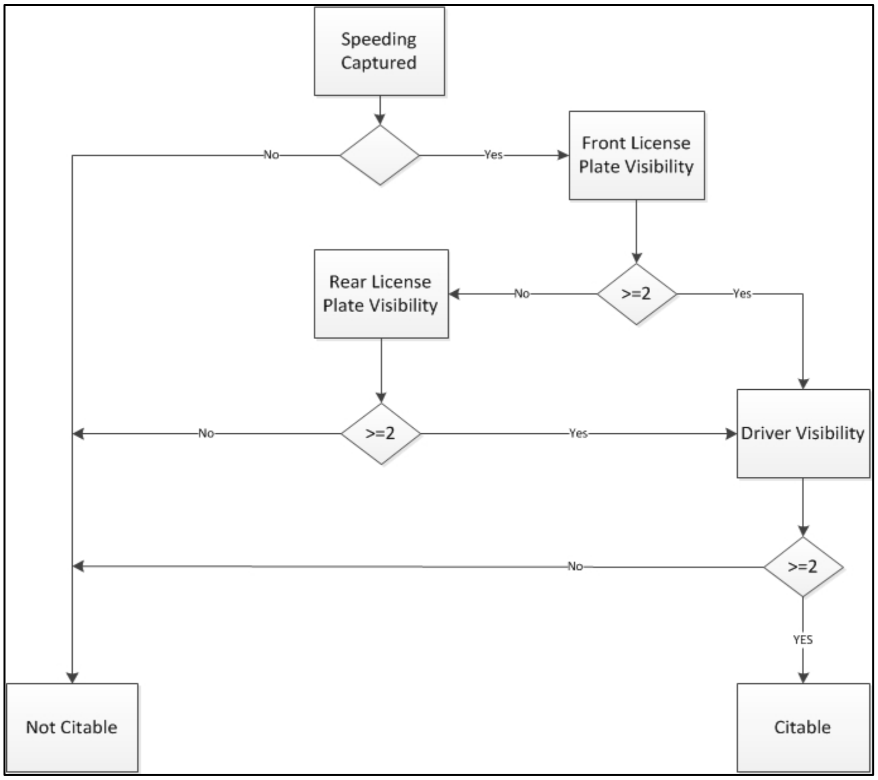

Figure 10. A Flow Chart to Determine if Captured Images are Citable.

The results in terms of the quality of images captured for each of the three vendor's PSE equipment is depicted in Figure 12. The scores indicated in this figure are average ratings using the scoring system described earlier. It is also clear from this figure that the PSE system equipment represented by blue color had an overall better quality of images.

Another important parameter analyzed was the number of tests in which the speed of the offending vehicle was recorded by the three PSE equipment tested (see Figure 13). As indicated in this figure, PSE equipment number two had the highest number of speeding vehicles captured (88%). PSE system equipment three, represented in blue, captured the least amount of speeding vehicles (60%).

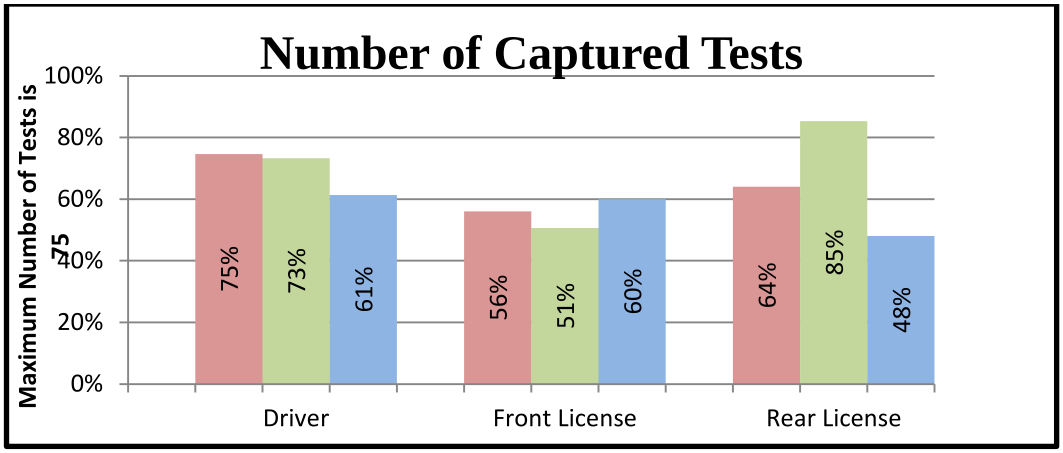

Figure 11. The Percentage of Tests (Events) Captured by Each PSE Equipment.

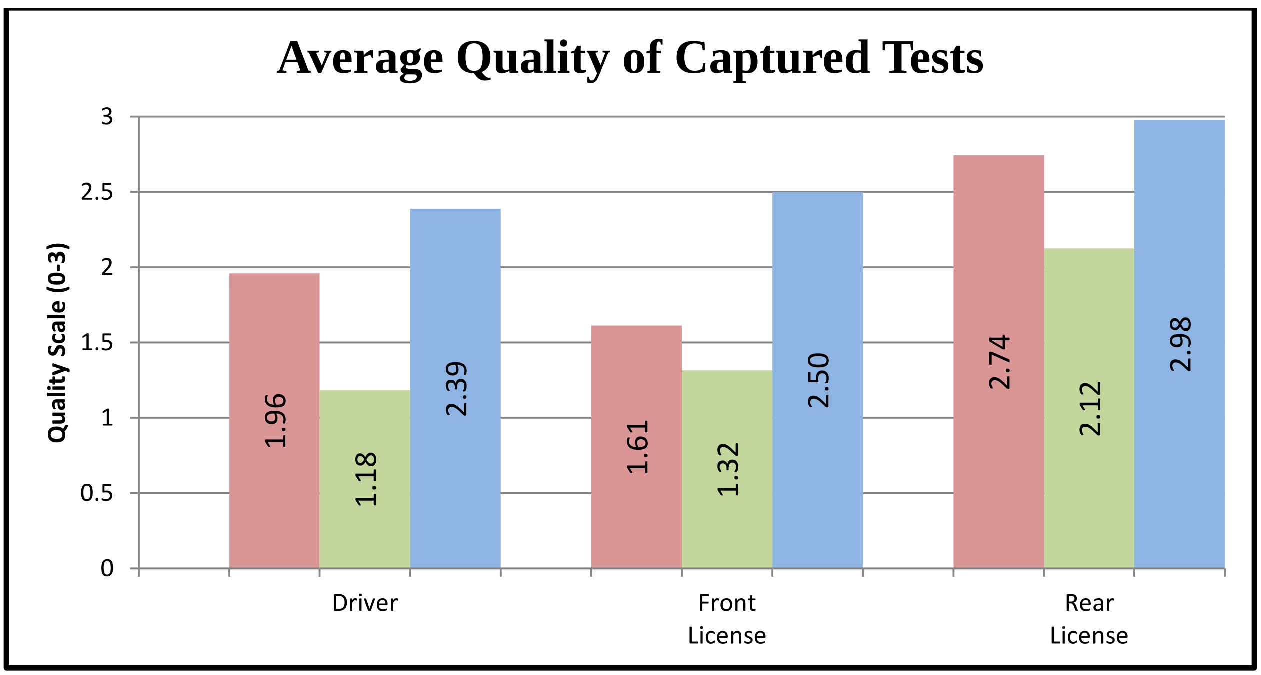

Figure 12. Comparison of Image Quality of Captured Tests among the Three PSE Equipment.

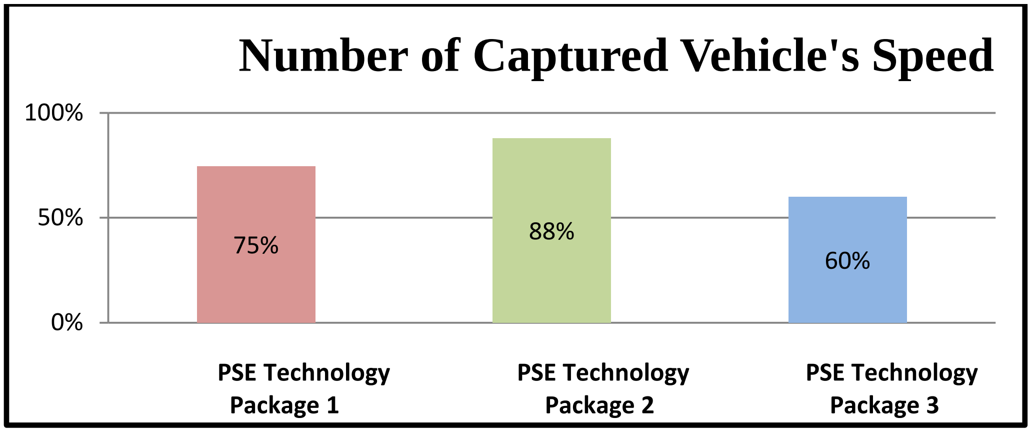

Figure 13. Percentage of Vehicle Speeds Captured by Each Vendor's PSE Equipment.

As indicated in the beginning of this chapter, the series of tests were broken down into daytime and nighttime tests. Test series one through four was conducted during the day. Test series five and six were conducted at night. The data for these test series were evaluated to compare the quality of captured images during daytime (light) versus nighttime (dark and/or illuminated). The results are shown in Figure 14 and Figure 15. Sixty five tests were performed during the day, and 10 tests were performed at night. PSE system equipment one (in blue) had the highest average image quality of the driver's face among the three PSE systems tested during the daytime tests. In the same timeframe, PSE system equipment three (in red) had the highest average image quality of the front license plate, while PSE system equipment two (in green) had the highest average image quality of the rear license plate.

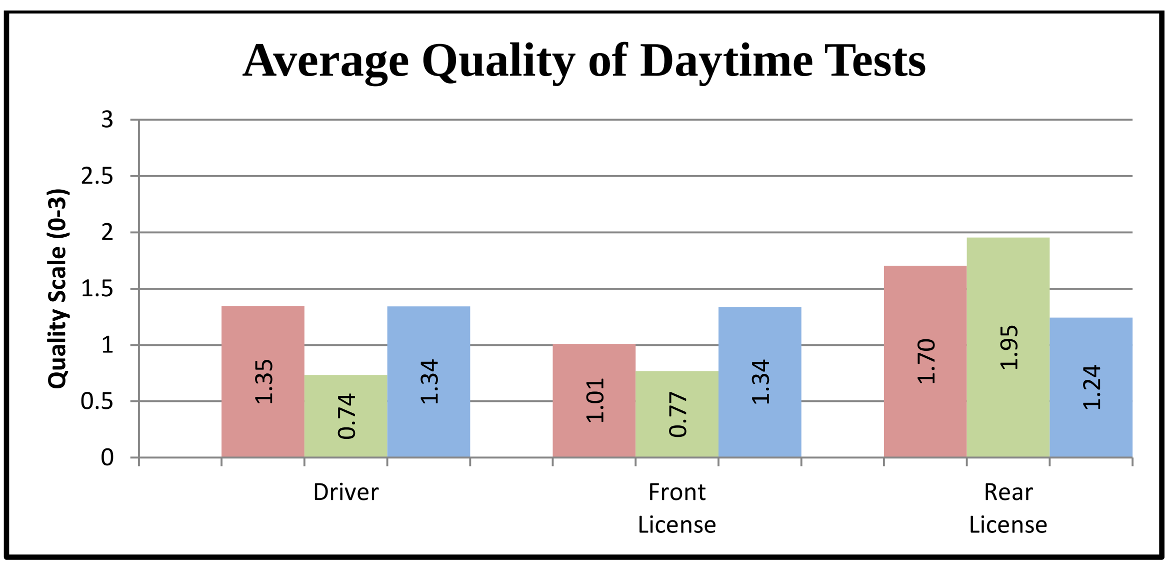

Figure 14. Average Image Quality in Daytime Test Series.

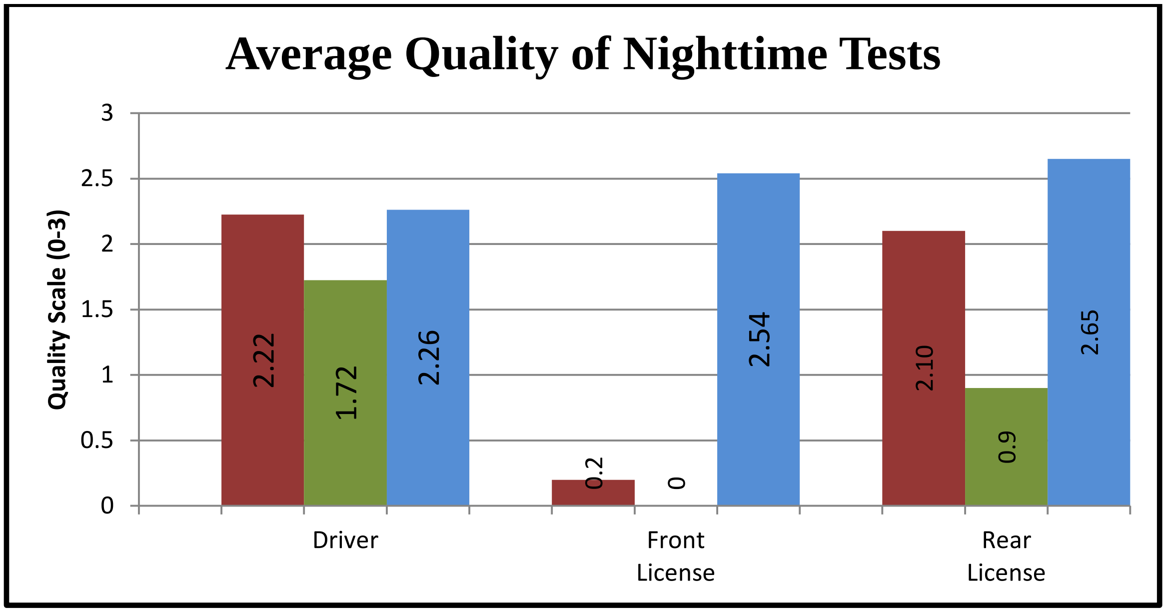

Figure 15. Average Image Quality in Nighttime Test Series.

Test data was also analyzed to evaluate the effectiveness of PSE system equipment in capturing fast moving vehicles in each of the three lanes. There were a total number of 75 tests conducted in all three lanes. In lane one, 38 tests were conducted; in lane two, 20 tests were performed; and in lane three, 17 tests were conducted. Lane one was the furthest from the PSE equipment, and, as the data in Figure 16 indicates, it was the lane for which all three systems missed the most violators. All PSE equipment tested, however, did relatively well in capturing the majority of the violators in lane two. The results for lane three, on the other hand, proved the most unpredictable or unrealistic of all three lanes. The trend in Figure 16 suggests that all three PSE systems' equipment tested should have had a better result in lane three than lane two; nonetheless, one can see a slight decrease of the number of speeding vehicles captured in the third lane. The challenge in capturing the data of vehicles traveling in lane three was determined to be the proximity of the cars when passing the PSE equipment. The CHP officers drove very close to the PSE technology packages, which can be adjusted for in actual highway implementation. The Radar/LiDAR beam angle of each PSE system is designed to detect the vehicles' offset by a huge vertical distance across the road; for this reason, the setup on the test site created a complexity in this scenario for all of the PSE equipment tested.

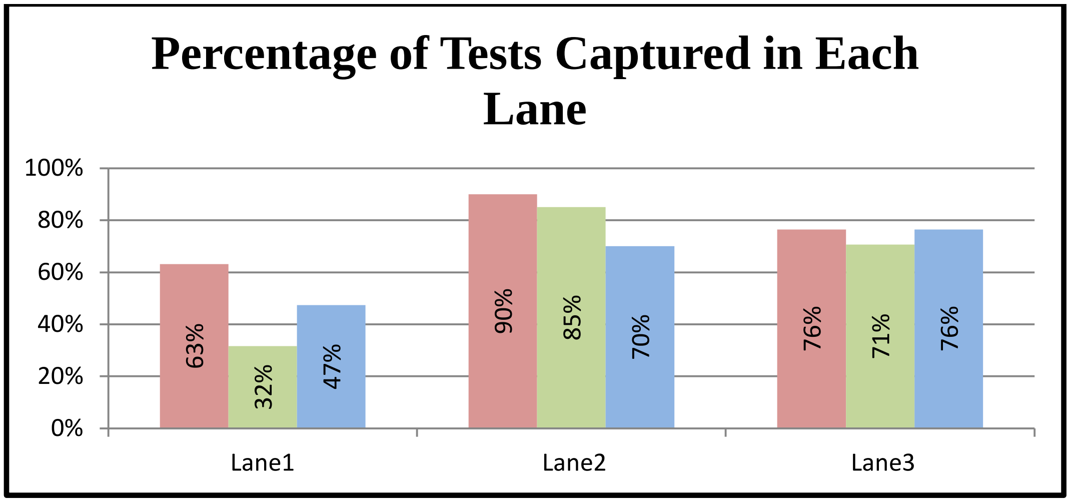

Figure 16. Percentage of Events (Tests) Captured in Each Lane by Each Type of PSE Equipment.

The data was also used to evaluate the number of captured events that would be potentially citable. The state of California requires that in any citation issued to a motor vehicle owner, the driver's information match the information listed on his or her driver's license. The type of information that will be searched for on a citation is a visible image of the license plate, either in the front or rear of the vehicle. This is necessary in order to be able to retrieve the driver's information from the Department of Motor Vehicles database. According to the existing court practice in California, a visible image of the violator, the vehicle license plate, and the speed at which the violator was found driving must also be presented and clearly stated on the citation in order for the court to accept the case and prosecute the violator.

The definition of a citable event as used here is the following:

i. The driver visibility evaluation score is greater than, or equal to, two (using raw images).
ii. The speed of the violator's vehicle is captured.
iii. Either the front or rear license plate's visibility evaluation score is at least two.

The results shown in Figure 17 indicate the percentage of all captured events by each PSE system's equipment that had the quality needed for the event to become citable based on the definition provided. It should be pointed out, however, that only raw images with no further enhancement were used in all the analysis provided in this report. There are usually post-processing techniques that all PSE system equipment can use in order to improve the quality of images, potentially increasing the yield on the percentage of citable events.

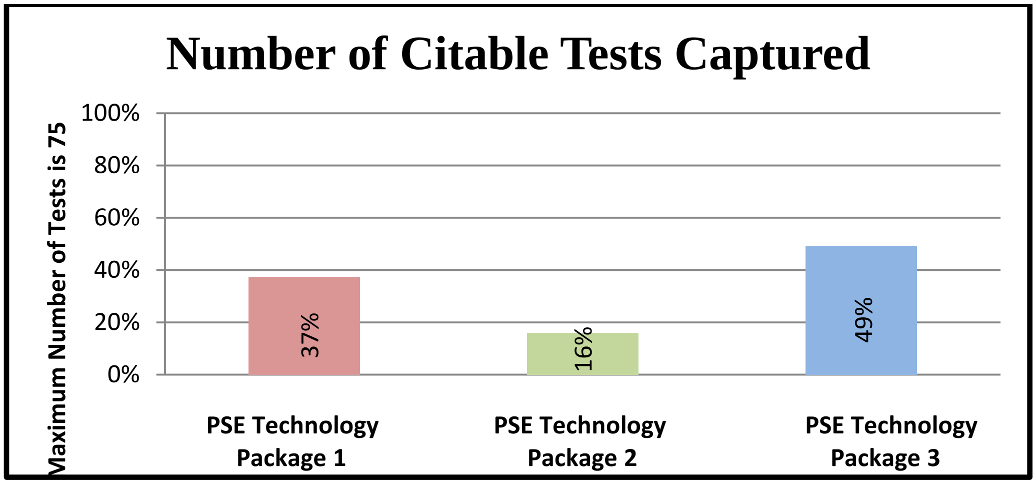

Figure 17. Number of Events that Would Be Citable in All the Tests Performed.

The analysis of citable events was further studied in terms of daytime versus nighttime tests. The results are depicted in Figure 18 and Figure 19. It is clear in these figures that the trend of citable images produced by PSE system equipment remained the same during the day and the night. In terms of citable images, PSE system equipment number three generated 45% during the day, whereas PSE system equipment number one produced only 32%, and PSE system equipment number two yielded only 14%. During nighttime testing, PSE system equipment number three captured a yield of 80%, followed by PSE system equipment number one with a yield of 70%, and finally, PSE system equipment number two, with a yield of only 30% citable images.

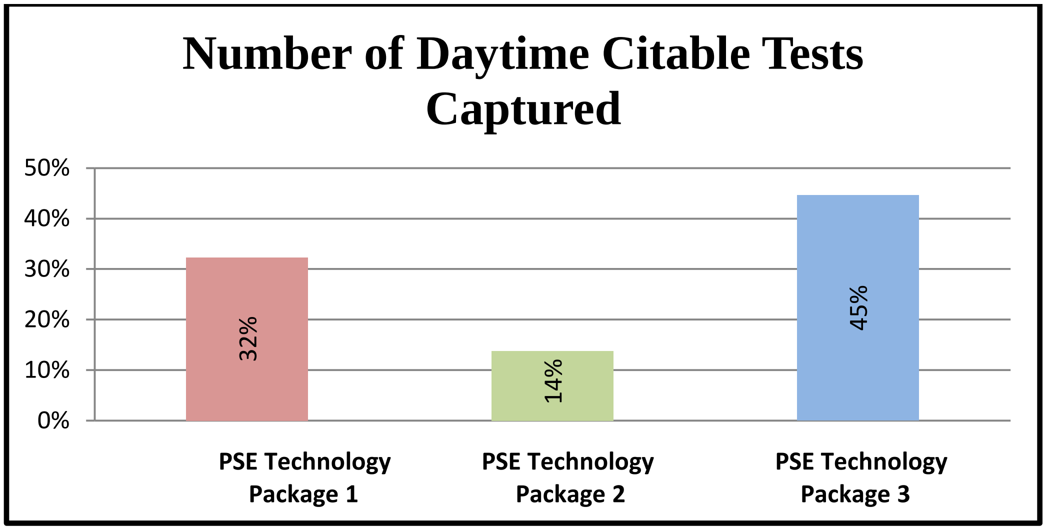

Figure 18. Percentage of Citable Events Captured in Daytime Tests.

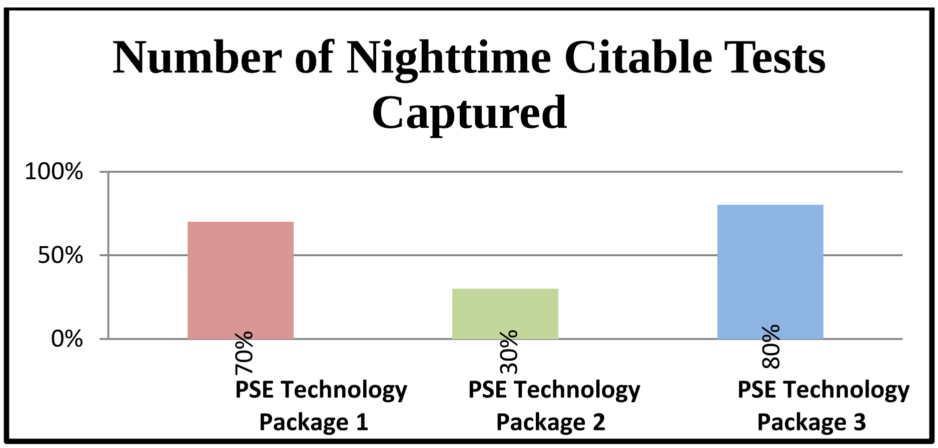

Figure 19. Percentage of Citable Events Captured in Nighttime Tests.

An overall analysis of the data in each of the tests was performed for each PSE equipment vendor tested. The results are summarized in Figure 20, where the percentages of citable and not citable events are indicated for each PSE equipment vendor, with color-coding used to describe the reasons an event was classified as not citable. It is notable that PSE equipment number two had 16% citable images with only 12% missed tests. Sixty four percent (64%) of the driver's images for this PSE equipment, however, were not useful or citable.

Comparing this data with the data in Figure 11 indicates that, even though PSE equipment number two was able to capture most of the tests, the quality of its images did not meet the citable criteria used here. The PSE Equipment number three, in contrast, had the most citable images (49%), but missed approximately 40% of all the tests conducted (according to the data in Figure 11). The results for PSE equipment number one remained neutral between PSE equipment numbers two and three.

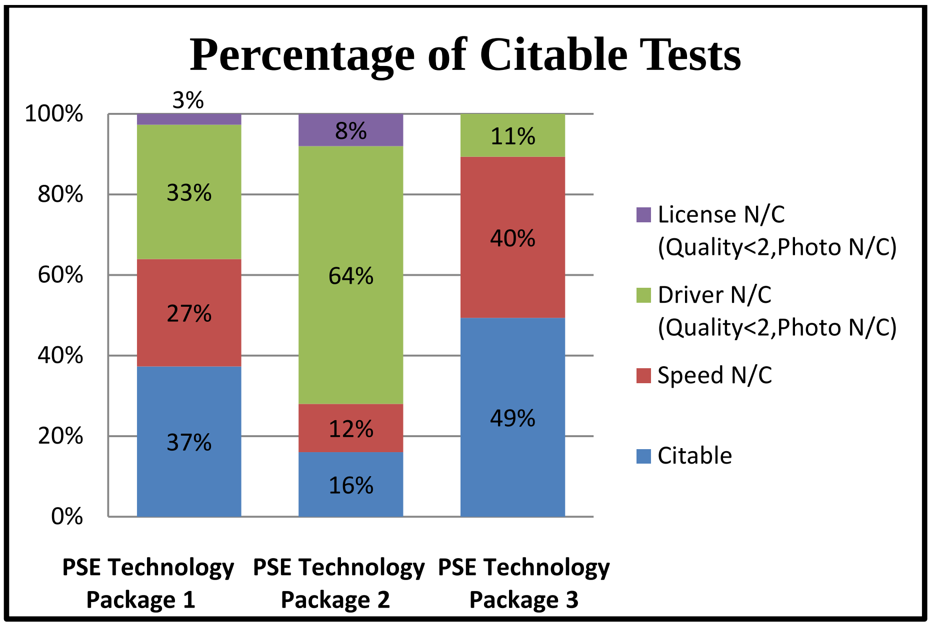

Figure 20. Break down of Citable and Not Citable Events for Each PSE Equipment.

Conclusions, Recommendations, and Limitations

The results of the tests discussed in this chapter indicate that there are commercially available PSE technologies that can be used effectively for speed enforcement in highway work zones. The test configurations and results provide data regarding the conditions and configurations under which the PSE technology can be most effective as a speed enforcement and safety improvement tool. Although the results in terms of percentages of citable events are below 50% for all PSE equipment tested, the number of events captured in any given period of time would far exceed the numbers that currently can be handled by on-duty police officers pursuing speeding drivers at the location—even in the case of PSE equipment number two, which had only 16% citable cases. This of course depends on the traffic volume at any location.

In terms of the limitations, it should be pointed out that all the tests were performed in the controlled environment of a test track facility with pre-planned test scenarios. Therefore, the results of the tests performed do not reflect actual scenarios, such as the driver's reaction to the PSE, any traffic congestion, or other highway issues. As a result, additional testing is recommended in an actual highway environment, which can lead into a better understanding of the effectiveness of PSE technology. This is discussed in the next chapter.

FIELD-TESTING

Field-testing was performed in Stockton and Los Angeles, California. The field-testing was performed in active highway work zones using the same three PSE technology equipment operated by their corresponding vendors as in the controlled testing. The details of the test plan, analysis, and results are discussed in this chapter.

Background and Rational for Testing

The goal of field-testing PSE technologies on a live freeway was to observe the performance of these PSE systems in real-world conditions. The research team was mainly interested in the following objectives:

- Gain an understanding of PSE system performance
    - measure how many speeding events are captured
    - out of the captured events, measure how many of these events could be used to generate a citation
- Gain insights on operational considerations for PSE deployment
    - obtain general information on the principal of operation for each different technology
    - identify challenges and potential solutions to issues during field deployment, such as set up requirements, training requirements, and system limitations

The average traffic speeds were measured using a commercially available radar-based mobile speed sensor known as iCones. Previous testing of iCones by the AHMCT research center indicated that iCones can provide consistent estimates of average traffic speed if used appropriately. Furthermore, iCones allows for rapid and non-intrusive sensor deployment for work zone data collection. In addition, a commercially available radar-based sensor, SmartSensor HD, manufactured by Wavetronix LLC, was used by the researchers to provide a baseline of traffic volume as well as the number of vehicles above various speed thresholds. The traffic volume was measured using the SmartSensor, which was set up on a mast at a height of approximately 20 feet above the road surface. While each PSE system tested also provided a log of all vehicles as seen by their sensors, their vehicle volume information was not as accurate as the AHMCT sensor due to their limited sensor installation height.

Test Set Up and Locations

The field tests were conducted on California State Route 99 (SR-99) near Stockton and on Interstate 210 (I-210) near Los Angeles. The test site near Stockton along SR-99 consisted of a segment of freeway with two live traffic lanes. At this location, the PSE vehicle was parked on the shoulder of the road immediately next to the live traffic lanes and was separated by a Jersey barrier, as illustrated in Figure 21. At this location, the speed at which the PSE system records the image of a speeding vehicle (trigger speed) was set to 70 MPH, which was determined to yield an acceptable amount of photographs for an image quality study.

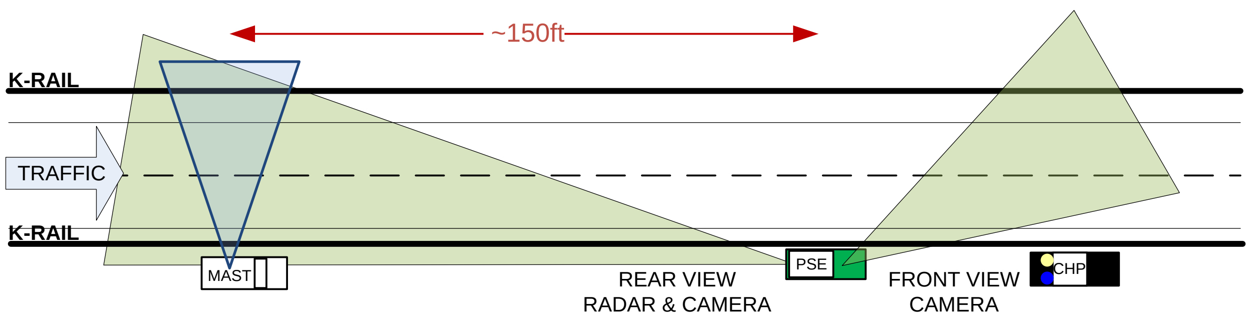

Figure 21. Layout for Field Testing of PSE Technology near Stockton, California.

The test site near Los Angeles was along a segment of the I-210 freeway with four live traffic lanes. At this location, the PSE vehicle was parked outside of the shoulder and was protected by a guardrail, as illustrated in Figure 22. In addition to the typical shoulder-side deployment, two out of the three technologies tested also participated in a brief testing of median-side deployment to address the concern regarding photographs of the driver's faces being obstructed by the A-pillar of their vehicles. For the shoulder-side deployment, the PSE system operators were allowed to adjust the trigger speed between 70, 75, and 80 MPH depending on the traffic conditions. In general, the trigger speed was adjusted up to keep the numbers of photographs manageable when the traffic volume was high and adjusted down to provide enough photographs for image quality when the traffic volume was low. In addition to deployment from the right-hand shoulder, the PSE system was also deployed briefly from the median in order to investigate whether or not photographs of the driver's image were blocked by the A-pillar of a vehicle.

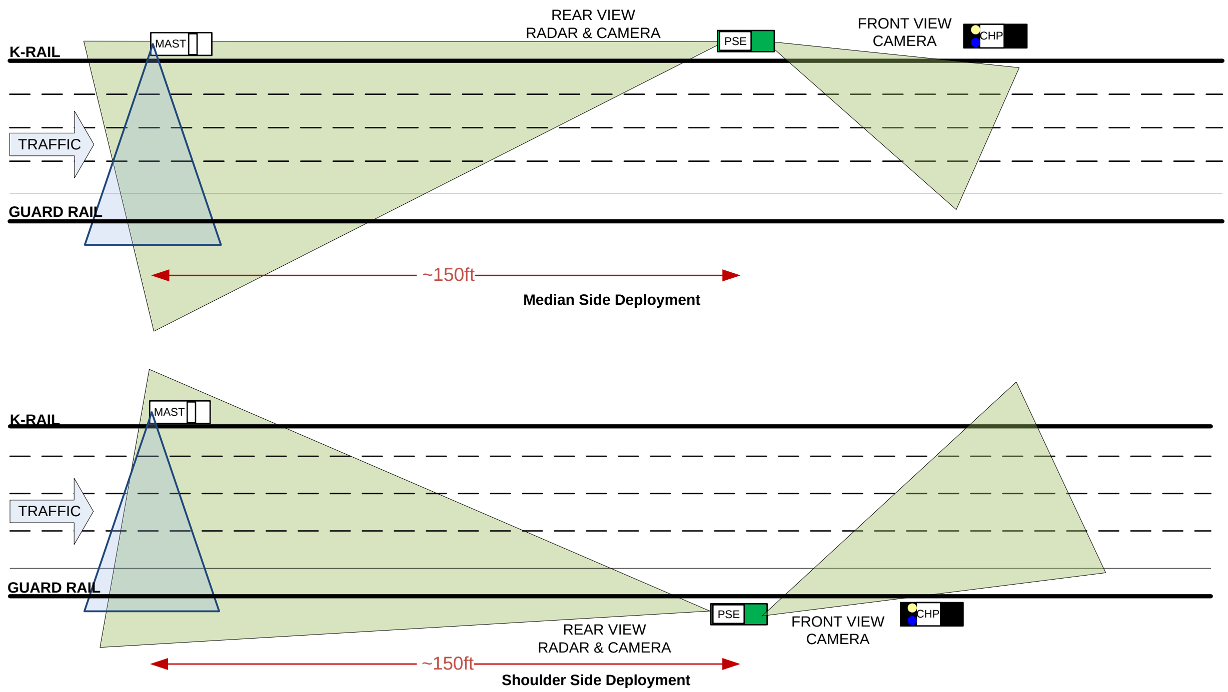

Figure 22. The Test Layout for the Field Test in Los Angeles Area.

Test Plan and Methodology

At both test locations, the same three PSE technologies from the controlled testing were examined. At the chosen locations, a long-term stationary work zone was available to support the testing, which lasted for 72 hours continuously at each location. Testing each day was divided into three shifts: afternoon (16:00 to 23:30), midnight (00:00 to 07:30), and morning (08:00 to 15:30). Each technology was rotated through all three different shifts, resulting in a total of nine technology-shift combinations during the 72-hour test period. The 30-minute breaks between shifts were intended to allow enough take down and setup time for a smooth shift change.

Prior to placing any equipment on the freeway, a meeting was conducted to communicate the objectives and procedures of the tests with representatives from the local Caltrans office and the CHP. The exact locations of PSE system deployment as well as other logistical issues were discussed in these meetings. The PSE systems were operated by their respective representatives from the participating vendors. A group of CHP officers also participated during the tests and were asked to observe the operation of the PSE systems and offer their opinions to the researchers at the end of each shift. During deployment, the operators were asked to record any interruptions to deployment, such as pauses needed to adjust camera settings. These logs were later collected by the researchers to reproduce the time intervals when the PSE system was functioning properly.

The data collected included the traffic log and images generated by each PSE system, which were obtained from the PSE system operator at the end of the tests. A total of 12,749 events were captured, with typically two to three images per event. An event is defined as an instance of a speeding vehicle having its images taken by the PSE system. The images obtained from the field tests were representative of what a law enforcement agency would obtain from each of the PSE technologies. The quality of these images was reviewed manually by AHMCT researchers and each event assigned to one of the following categories:

- Category I: clearly citable
  - Driver image shows position and geometric characteristics of facial features
  - Front or rear license plate is fully legible
- Category II: likely citable
  - Driver image shows position of facial features
  - Front or rear license plate is fully legible
- Category III: plate only (non-moving citable)
  - Driver image does not offer identifying information
  - Front or rear license plate is fully legible
- Category IV: not citable
  - Both front and rear license plates are illegible (poor image quality, obstructed or missing)

In addition to the quantitative data, field observations about the PSE systems were made by the researchers and CHP officers who participated in this study. These observations provided valuable insights into the details of the operation of the PSE systems and are incorporated into the results of the study.

Test Data and Analysis

Vehicle Detection Rate of PSE Systems

The PSE systems can only detect a portion of the traffic due mainly to shadowing and other difficulties associated with each system's speed sensors. Since the SmartSensor used by AHMCT researchers was mounted in an elevated position, its measurement of traffic volume was more accurate due to less chance of shadowing. The number of vehicles at or above trigger speed as seen by the SmartSensor is used as a baseline to compare with the number of vehicles detected by the PSE systems (which were obtained using the traffic log from each PSE system). Since both the SmartSensor and the PSE systems had some down time during testing, data was only taken during time periods when both systems were functioning properly. The down-time periods were identified by calculating the vehicle gap using timestamps provided by each sensor. When the vehicle gap was larger than 60 seconds during the day or 120 seconds during the night, a manual review of the video footage of the test site was conducted to confirm if an actual break in the traffic occurred. The total number of vehicles at or above the trigger speed from both the PSE system and the SmartSensor during these time intervals when both sensors were properly functioning is shown in Figure 23. In most shifts, the PSE system captured fewer vehicles at or above the trigger speed than the SmartSensor, as expected.

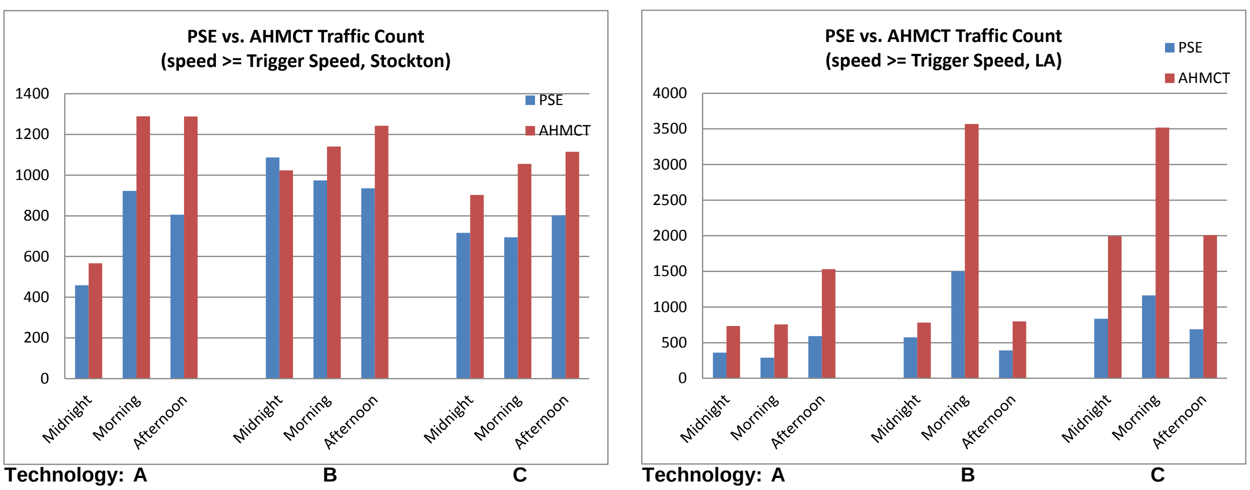

Figure 23. Number of Vehicles At or Above Trigger Speed: 70 MPH in Stockton and between 70 to 80 MPH for Cars and 62 to 66 MPH for Trucks in the Los Angeles Area.

The PSE systems did not generate an event for every detected vehicle at or above its trigger speed. If the quality of speed-reading was unacceptable, the PSE systems would not take pictures of the vehicle, even if it was traveling at or above the trigger speed. The percentage of events generated over all vehicles at or above the trigger speed is shown in Figure 24.

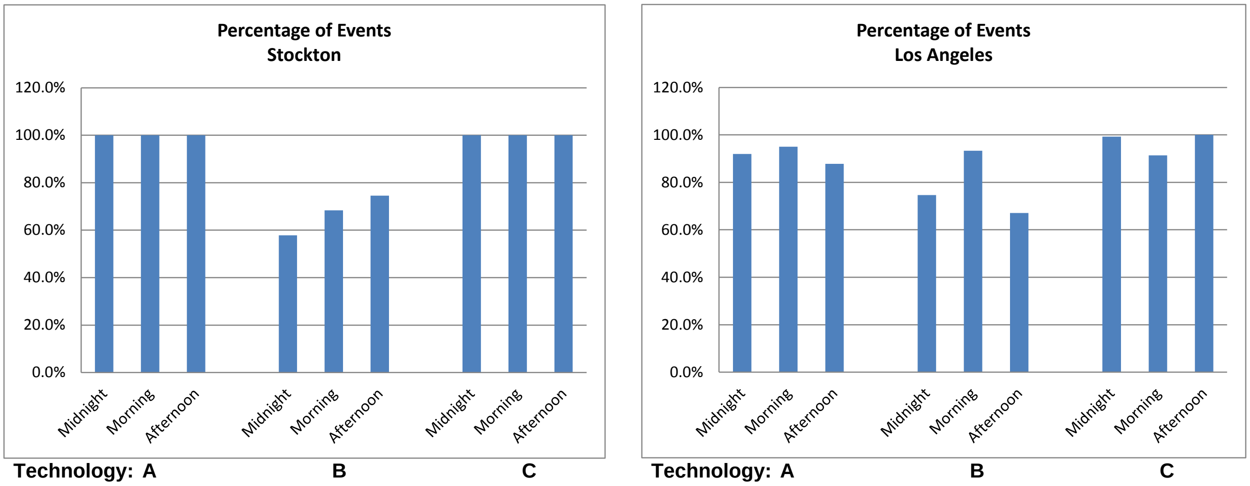

Figure 24. Percentage of Events Generated At or Above the Trigger Speed by the PSE Systems.

Image Quality Assessment

In order to assess the quality of images, the scoring system developed in the controlled testing was modified in order to relate to geometric and shape features for facial images and was redefined as follows:

Score Requirement:

0 *If the facial image had 0 to 1 out of 3 major identifiers: gender, age bracket, and skin tone.*

1 *If the facial image had 2 to 3 out of 3 major identifiers: gender, age bracket, and skin tone.*

2 *If, in addition to the requirements of score 1, one would be able to see facial location of features such as eyes, nose, and mouth in the facial image.*

3 *If, in addition to the requirements of score 2, one would be able to see geometric characteristics of facial features such as eyes, nose, and mouth in the facial image.*

For the license plates, all alphanumeric characters had to be recognized in order to rank at least a "2." If one had to guess, then the photo rated a "1." When the photo was clear and the license plate easily read, then the photo rated a "3."

Due to the high volume of events obtained from the testing (6,784 events in Stockton and 5,965 events in Los Angeles), a sampling system was used, and only a portion of these events were subjected to a manual assessment of image quality. The proportion of images belonging in each category was estimated by calculating the proportion of categories in the sampled images. The standard error of the estimated proportion varied with the value of the proportion, being largest when the proportion was 50% and smallest as it moved closer towards 0% or 100%, as shown in Figure 25.

A pilot study was conducted to get a rough estimate or proportions of vehicles in Category I (CAT I) and II (CAT II) in order to find a sufficiently large sample size. Using 20 events from each shift during the pilot study, the proportion of vehicles belonging in either Category I or II varied between 40% to 84% in Stockton tests and 16% to 40% in Los Angeles tests. Given the close proximity to 50%, at which the uncertainty of the estimate is highest, the sample size was determined assuming 50% of vehicles are in Category I or II. The sample size which satisfied a 5% error margin at a 95% confidence interval was calculated to be 384 using a Java applet [24]. Out of all 18 shifts from both test locations, three shifts in Stockton and one shift in Los Angeles had less than 384 events, in which case all of the events were manually reviewed. The least number of events from a shift was 285, which changed the error margin to 0.58 at a 95% confidence level.

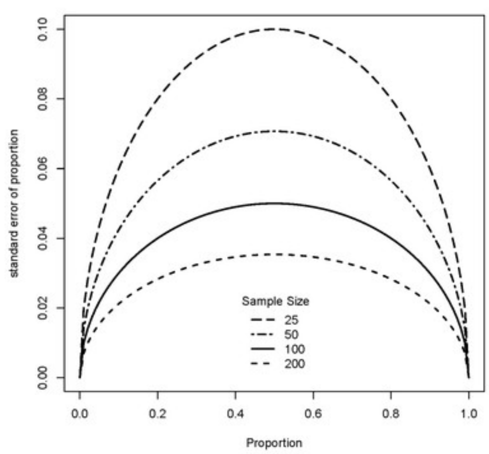

Figure 25. Changes in the Standard Error of Proportion with its Value [24].

Once the sample size was established, four different individuals were used to score them. These individuals were all trained and their work was reviewed to reduce variations in their interpretation of images.

Each group of events from a shift was reviewed separately by four individuals and the percentage of events for each category was then averaged across the four reviewers. Category I corresponds to those images that are definitely citable based on the image quality. In reviewing the scoring of the images, it was determined (based on a small sampling of the data) that at least 50% of Category II images would also be citable. The results presented in Figure 26 summarize the percentages of events in Category I, the sum of percentages of Category I, and 50% of Category II. It should be noted, however, that the percentage of citable cases in Category II images was based on sampling a small amount of the data and that, in the real world; the results can potentially be higher or lower. The sum of Category I and all of Category II are important since these values represent the estimated probability of having a clearly citable event (CAT I) or at least a likely citable event (CAT I + CAT II), provided that an event is generated by a particular PSE technology. Considering the 5% margin of error, the proportion of CAT I events are negligible, but a significant proportion of CAT I + CAT II events generated by the vendor still remains.

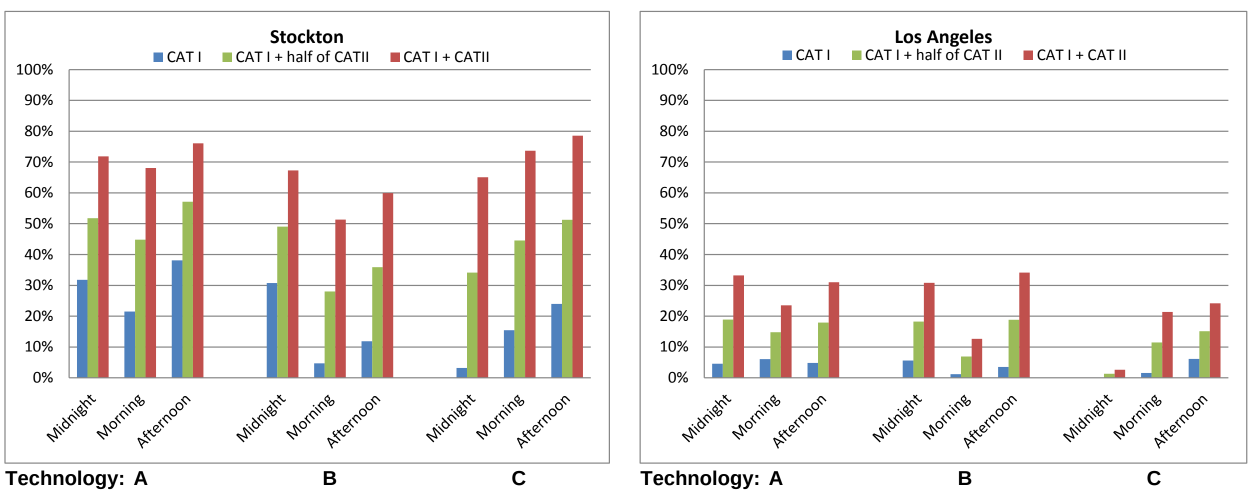

Figure 26. Parentage of Category I, Category I plus half of Category II, and Category I plus Category II Vehicles Traveling above the Trigger Speed.

Using the information provided above, the likelihood of a vehicle traveling at or above trigger speed resulting in a CAT I or CAT II event or their combination can be obtained by multiplying the rate of PSE system detection (calculated using the numbers in Figure 23) by the percentage values in Figure 24 and Figure 26. The result is shown in Figure 27 and can be used as a guideline to estimate the number of good quality events from PSE systems on similar roadways with similar trigger speeds, if the number of vehicles at or above trigger speed can be measured.

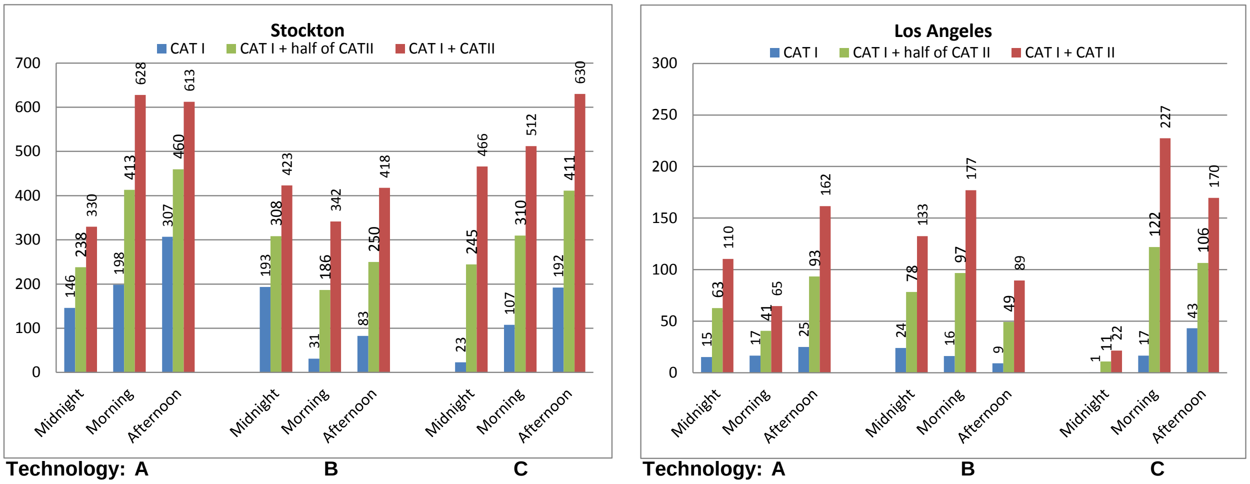

Figure 27. Number of Category I, Category I plus half of Category II, and Category I plus all Category II Vehicles Traveling above the Trigger Speed.

The data in Figure 27 shows that when one considers Category I plus one half of Category II cases, the PSE systems A and C outperformed PSE system B in Stockton, but in the Los Angeles area the PSE systems all had relatively comparable overall performances. Furthermore, when one considers the themed range of Categories (i.e., Category I plus one half of Category II) as a potentially citable event, it is clear that, although the percentages indicated in Figure 26 may be low, the number of citable events are high, as shown in Figure 27. Each of the shifts indicated in these figures is an eight-hour shift. The data for Category I plus one half of Category II in Figure 27 indicates that, for example, for Stockton in the morning shift, the number of potentially citable events ranged from 23 to 52 per hour. In Los Angeles, similar numbers for the morning shift had a range of 5 to 13 per hour. These numbers are all higher than the time needed for the CHP pursuit and ticketing of speed violators (estimated at 3 per hour for a single CHP unit). It should be pointed out, however, that when a CHP unit is used, it also acts as a visual deterrent to speeders and results in the reduction of the number of speeders, which is the ultimate goal in improving work zone safety.

Since the SmartSensor used by AHMCT researchers has limitations and cannot detect all of the vehicles on the freeway, the estimates on the total number of speeding vehicles provided above are slightly different from the true value. In addition, there are two sources of inaccuracies in the results presented above. First, a small number of extra events are generated by the PSE operator during system setup (and sometimes mid-deployment) to check picture quality which are not associated with a speeding vehicle. However, the amount of these extra events is very small, about less than 10 per shift, which has minimal if any contribution to the final figures. Another inaccuracy could come from the fact that the ratios of categories are estimated based on a subsample of all images, but even then the error would be small.

Image Quality by Lane

During the field-testing, it was observed that the quality of images from PSE systems declined as distance between the speeding vehicle and the camera increased. In order to understand the severity of image degradation due to distance, the average score of driver face image was arranged by lane in Figure 28 and Figure 29. The images obtained during the test near Los Angeles revealed large differences in the average score of driver image quality between lanes that are farthest (#1 lane, 5 lanes away) and closest (#4 lane, 2 lanes away) to the PSE system. The average score for the two lanes involved in the Stockton tests are very similar due to the close proximity of both lanes to the PSE equipment.

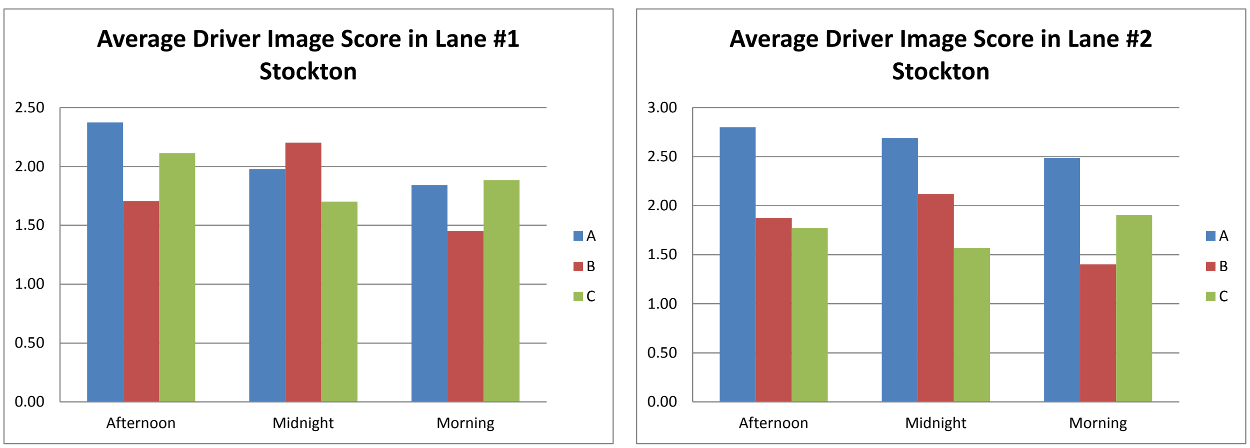

Figure 28. Average Driver Image Score by Lane in the Field Test Performed in Stockton Area.

Deployment of PSE in the Median – A Brief Test

Some of the PSE technologies tested were deployed from the median side of the highway, thus minimizing its distance from the number 1 lane, which should have more speeding vehicles than the shoulder lanes. However, an issue with this configuration is that photographs of the driver's face are often obstructed by the A-pillar of the speeding vehicle, as seen in Figure 30. PSE systems from two technologies participated in a brief demonstration of the severity of A-pillar obstruction when PSE is deployed from the median side. The demonstration involved two PSE systems and lasted about 40 minutes for one PSE system and 2.5 hours for the other. About 52% of images from one PSE system had the photographs of the driver's face obstructed by the A-pillar, and about 9% of images from the other PSE system had the same issue. From this brief testing, it was observed that the issue of A-pillar obstruction was significant for some PSE technologies, while for others it was not a large concern.

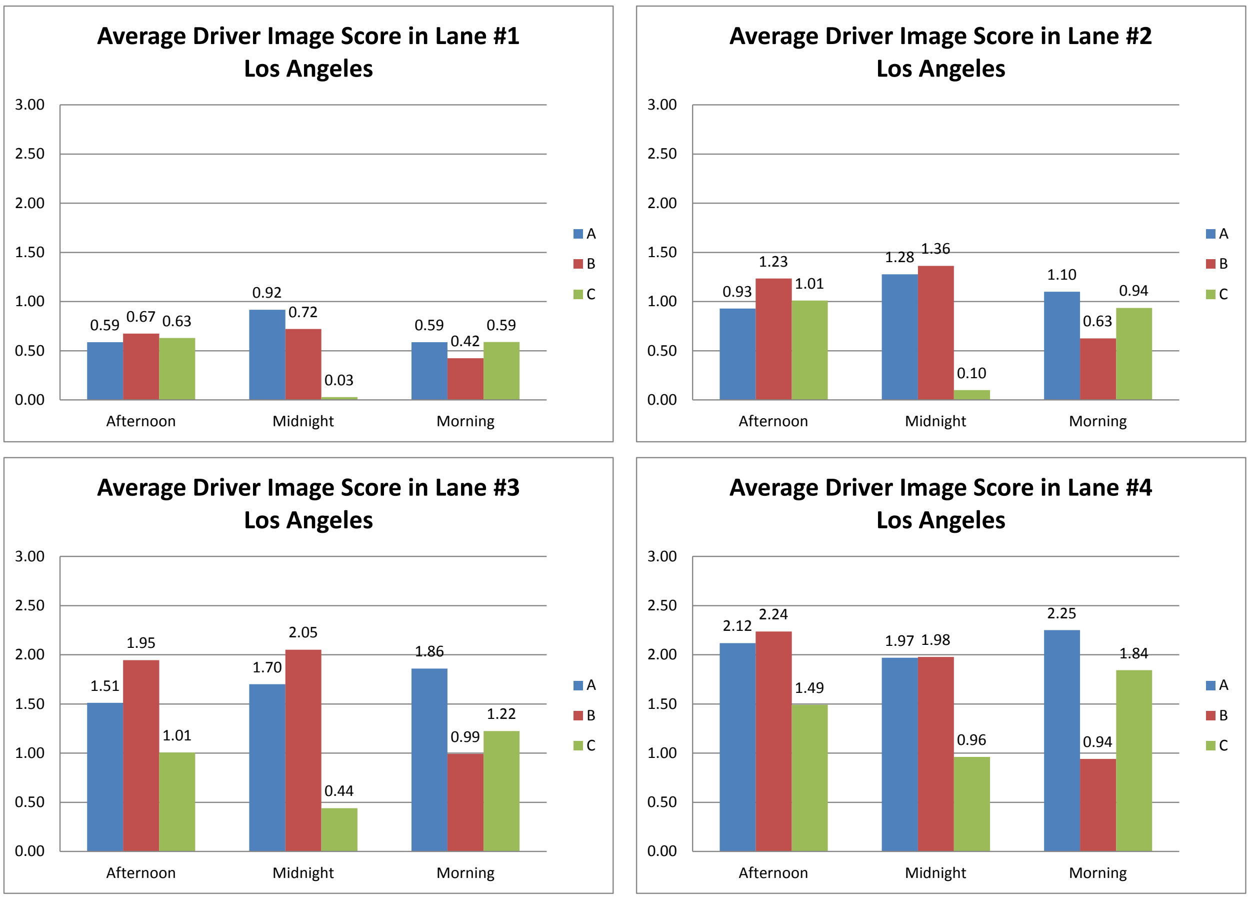

Figure 29.Average Driver Image Scores for Field Tests in Los Angeles Area.

Figure 30. An Example of A-Pillar Obstruction.

POTENTIAL CONCEPT OF OPERATIONS FOR CALIFORNIA

Background

The systems engineering approach described in the Systems Engineering Guidebook for ITS (www.fhwa.dot.gov/cadiv/segb/) defines a Concept of Operations (ConOps). The ConOps documents the total environment and use of the system to be developed in a non-technical and easy-to-understand manner; presents this information from multiple viewpoints; and provides a bridge from the problem space and stakeholder needs to the system-level requirements.

The ConOps document results from a stakeholder view of the operations of the system being developed. This document presents each of the multiple views of the system corresponding to the various stakeholders including operators, users, owners, developers, maintenance, and management. This document can be easily reviewed by the stakeholders to get their agreement on the system description and also provides the basis for user requirements.

Stakeholders are the people for whom the system is being built, as well as anyone who will manage, develop, operate, maintain, use, benefit from, or otherwise be affected by the system. The application of PSE has a wide range of shareholders beginning with the general and traveling public, through the personnel directly involved in using the systems and processing the resulting tickets. The ConOps developed in this research primarily reflects the interest of the following stakeholders: CHP, Caltrans, PSE system vendors, and the public.

PSE as an Extension of COZEEP/MAZEEP

The objective of PSE is to improve speed limit compliance and safety in work zones. This is envisioned as an extension of the COZEEP and MAZEEP programs, whereby the presence of a CHP officer in a marked patrol vehicle can cause drivers to slow down out of fear of getting a speeding ticket.

By automating the process, the rate of ticketing will potentially increase since the COZEEP/MAZEEP or other assigned patrol vehicle can stay in place and ticket vehicles concurrently. Presently, a CHP officer assigned to pursue violators can only ticket once every 20 minutes. The process of pulling over a vehicle and approaching the unknown driver and passenger(s) while being exposed to fast moving traffic is very hazardous to the officer and potentially the traveling public. The use of a PSE system has the potential to prevent these dangers from impacting safety in work zones.

Planning PSE in a Work Zone

Conceptually, the PSE system would be placed wherever MAZEEP/COZEEP units are positioned, but PSE placement options are more restricted in two ways. First, a PSE system needs to be carefully placed in or near a highway work zone so that the system works correctly. Second, it cannot be readily moved during the course of a shift of highway work.

The fundamental nature of work zones is that they are very dynamic environments. Maintenance work zones tend to be more transient than construction work zones. Maintenance zones tend to be set up and taken down in shorter shifts and the crew and the MAZEEP officer are usually behind a line of cones. Construction work zones often have work areas blocked off by K-Rails, barrels, and cones. Construction zone operations are typically in place for days at a time. Often, the work is done at night when additional active lanes will be closed off by traffic cones to allow the movement of equipment and workers beyond the K-rail protected areas. Generally, the CHP vehicle is placed upstream of the roadwork operation to be most effective, since the traffic speeds up soon after passing the CHP vehicle. Roadwork can be relatively stationary, such as when building an overpass, or it can move continuously, as in the case of paving.

The quicker a PSE system can be set up, the easier its implementation in work zones. A PSE vehicle will be subject to being rear-ended by errant vehicles. The positive protection from a guardrail or K-rail is ideal but often not achievable. During set up, the PSE operator may have to exit the vehicle to align it with respect to the fog line and adjust equipment. The PSE vehicle needs to be placed in a safe location and, when possible, have positive protection. The PSE vehicle needs to be located such that it can readily evacuate its location by moving forward to quickly move onto the roadway. This is a basic procedural requirement for CHP officers to ensure their safety and their ability to respond. A location that could trap the vehicle in place due to construction activities or physical barriers is not acceptable.

The PSE system needs to be placed on straight sections of roadway away from on and off ramps. Roadway curvature in the vicinity of the PSE will negatively affect system accuracy. Additionally, systems need to be located on surfaces with limited camber. Typically, the area on the outside shoulder has more options for PSE placement than the median, and CHP vehicles are discouraged from positioning in medians. Caltrans safety requirements restrict the placement of roadwork operations on both sides of the roadway in some types of operations. This further restricts PSE placement.

Unprepared shoulders such as those behind guardrails may not be level enough for a PSE system. Surfaces may also be at a different elevation than the main road. Caltrans K-rail barriers are 32 inches in height, and other types of barriers or walls can be 36 inches tall or more. A PSE system has a maximum barrier operating height over which it can operate. The combination of elevation changes and barrier height can be limiting.

The placements of the PSE systems at field test locations in Stockton and Los Angeles are depicted, respectively, in Figures 31 and 32. These site placements are representative of ideal locations for PSE systems. For ideal operations, the PSE system should be near the active roadway edge, as shown in the Stockton site in Figure 31. Safety requirements assume that an unpinned K-rail will move three feet if impacted. The vehicle or any person walking along the vehicle must be outside this zone.

Figure 31. Placement of PSE in Stockton Showing Minimum Distance to Traffic.

In the field test site in Los Angeles, the distance between the PSE system and the first active lane was more typical, as shown in Figure 32. Note that a line of cones was later placed along the shoulder edge to encompass the parked CHP vehicle.

Figure 32. Placement of PSE in Los Angeles Showing Typical Distance to Traffic.

Another perspective to consider in the placement of a PSE system is that of the traveling public. While generally the public is in favor of efforts to maintain the safety of persons working on roadways and accepts the need to enforce speed laws, placing PSE systems a large distance beyond the work activities may cause people to consider it a speed trap. The placement of systems should be affected by public perception.

The PSE systems have additional limitations to placement. For example, in discussions with engineers, it was pointed out that sometimes the radar systems are negatively affected by reflections off walls or fencing. This problem was presented as a rare and random occurrence. Each system can accommodate some road curvature, which should be defined in specification and operating requirements. Defining the worst-case geometry, when operating behind a barrier, is an important consideration in a PSE specification and affects the location of sensors and cameras on the vehicle.

All three systems tested integrated a 'Location Code' within their data package and system operation procedure. It is an important part of the standard evidence package since it includes relevant data such as geospatial information, speed limit, and traffic direction. Locations are the primary data entry points, and they should be defined before placing the PSE system in the field. In typical usage, PSE operators select a location from a predefined menu of Location Codes. This process may require additional planning and restrictions in PSE placement, which has to be defined in specifications and the development of an evidence package format. Caltrans resident engineers, maintenance supervisors, CHP, and others that presently plan the placement of the COZEEP/MAZEEP vehicle need to consider the unique requirements of the PSE technology when deploying such a system. Significant additional planning and coordination is required.

Signage for PSE Deployment

Signage indicating the presence of PSE was considered important to the demonstration of PSE in the field-testing for this research. Since the California MUTCD (Manual on Uniform Traffic Control Devices) has no provision for PSE or signage, an administrative review process was required to define and place signs for the field test. This could not be completed within the projected testing schedule and no signage was used during the field test. Signage is considered critical to the fair and effective implementation of PSE and needs to be designed for any future implementation.

No recommendation for signage beyond that of the CHP concept has been made. The original concept defined by CHP was that approaching drivers would be presented with three signs or messages warning of the presence of the PSE system. A speeding driver would have three chances to reduce speed before being captured by the system. Based on the Illinois system, the last sign would be a CMS (Changeable Message Sign) on the PSE vehicle indicating the speed of approaching vehicles.

During the early stages of field test planning, the configuration settled on was that signs would be interspersed among the standard signs in the Advance Warning Area. Tentatively, the optional CMS at the beginning of the work zone would be the first indication of PSE. Orange diamond roadwork signs, as shown in Figure 33, would be added as necessary for a total of three warnings.

It was expected that the signage itself would slow traffic down since the pattern set in other states would be reasonably followed in California construction sites. At least one semi-permanent sign would be near the beginning of the work zone indicating that PSE was present. A second temporary sign would be about 300 feet upstream of the PSE system, and then the PSE system would have a sign or message on the vehicle. Based on observations of traffic flows, it is likely that placing strong messages using CMS and speed-readings further upstream would avoid the effects of last-minute panic braking. In all cases discussed, the PSE vehicle would be clearly indicated as a CHP vehicle.

The implementation effort needs to be considered when planning for signage placement. Signage on the PSE vehicle is easy to implement, but any temporary signage upstream will add significant time and effort in the setup process.

Signage is expected to reduce the speeds of approaching vehicles. It is reasonable to expect that, if PSE is randomly implemented in work zones, speeds will be reduced as a matter of habit, and any signage indicating the PSE will be a strong reminder to slow down.

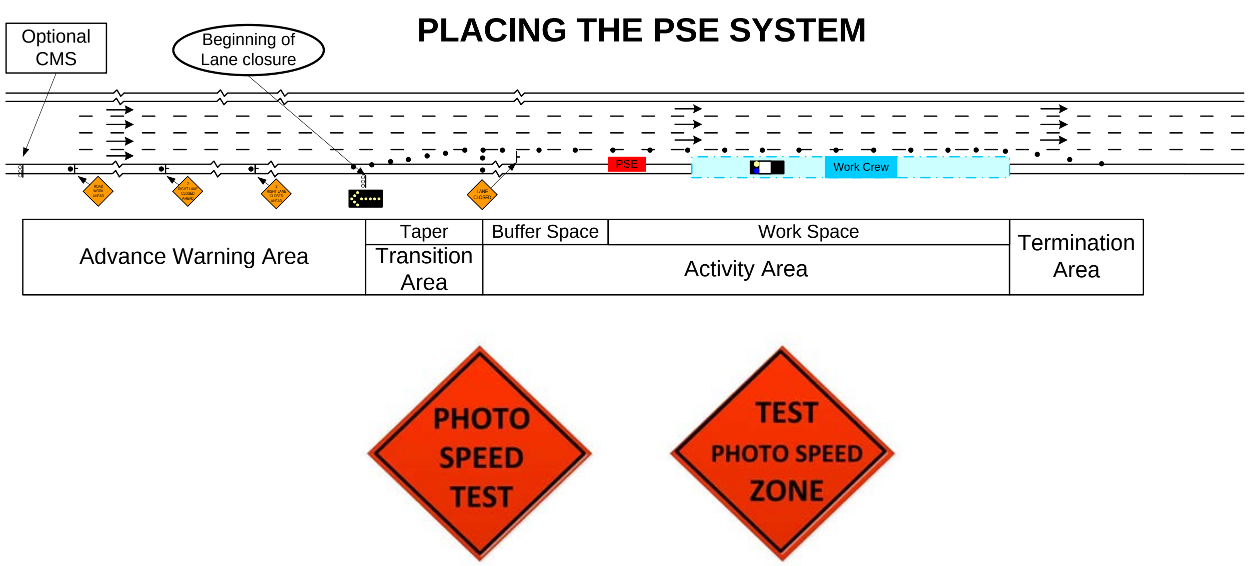

Figure 33. Signage to be Placed Ahead of PSE Detection Area.

<u>System Setup and Operation</u>

The demonstrated vehicle-based PSE systems are easily driven to the site and set up. Setup time was 15 to 30 minutes, and it is reasonable to expect that it would take 15 minutes in regular operations. Some PSE systems require the alignment of the vehicle to the roadway, which takes time and requires some exposure of the operator to the passing traffic. This is normally achieved by measuring and equalizing the distance between tire sidewall to fog line at the front and rear tires. This measurement requires the operator to get within a few feet of the fog line. In the field-testing in the Los Angeles area, the distance was measured with a tape using an intermediate painted string line, as shown in Figure 34. Due to the heavy traffic, a CHP officer placed a traffic break for the researchers. In the case shown, the difference between front and rear measurements was to be no greater than one inch. Adjustments were made for the difference in the track width of the front and rear axle. Since the effect of steering the vehicle into position causes both ties to move laterally, the alignment process requires some practice.

The alignment process is defined by the vendor and is very important to the accuracy of speed measurement. One vendor simplified this process by using a camera and a second alignment target. In cases where the system is set up in the same location repeatedly, marks would be placed on the road so the operator could easily position the vehicle (Figure 34). The LiDAR-based PSE system is unique because it scans the approaching traffic and defines the orientation of lanes in its internal software. This has the advantage of not exposing operators to the measurement process, but does not necessarily reduce the setup time.

Figure 34. Alignment of a PSE System Vehicle with Respect of the Road Edge Using a Line Parallel to the Fog Line.

<u>Configuring the PSE Vehicle</u>

Vehicle Platform

The selection of the base vehicle is based on the customer's preferences and the minimum packaging requirements for the PSE system. Each system had several 'boxes' that need to be installed on the interior and exterior of the vehicle. This included RADAR or LiDAR sensors, at least one rearward driver/face shot camera and one forward license plate shot camera, associated flashes, computers, batteries, power electronics, and an operator interface screen (Figure 35). Radar units and flashes were located on the vehicle exterior. The demonstrated PSE systems were integrated into three different types of vehicles: a small van and two small SUVs. The van and one of the SUVs had rear-facing seats for the operator. Both small SUVs were considered too small for the system by the officers. Officers are laden with duty belts and other safety gear that make it difficult to work in smaller vehicles. Conceptually, the larger Sports Utility Vehicle (SUV) or a small van would be the minimum-sized vehicle required for the PSE system. Officers stated that it is likely a PSE vehicle would be a dedicated vehicle and not integrated into the standard CHP Interceptor unit, which has no room for extra equipment. Additionally, the standard vehicle is subject to shock and vibrations that might damage PSE hardware.

Figure 35. Example of PSE System Components.

In the course of setting up and when making adjustments to the camera, the operator must access the rear-facing side of the system. During the field-testing, hardware was sometimes accessed from the interior of the cabin, which required some dexterity to crawl and reach. This would not be considered an acceptable procedure under normal circumstances. If no physical measurements to the road were required, conceptually a PSE system could be operated from within a large van without exiting the vehicle. This might be preferred, but given the options presented by the vendors and to minimize restrictions on vehicle configurations, it is recommended that the operator be expected to exit the vehicle for setup and some adjustments during the normal course of a shift. The vendors expressed that there is no standard configuration and customization to the CHP specifications is expected. At least one of the vendors detailed the design effort required to securely mount components for crashworthiness. It is expected that CHP would be directly involved with the vendor in the design of a system.

Seating for Operators

A minimum of two seats would be required to allow for a second officer or trainer. There is also a preference for forward-facing seats. Two different seating layouts were demonstrated. In two of the systems, the seat next to the driver was rotated for the operator to look rearward while operating the system, as shown in Figure 36.

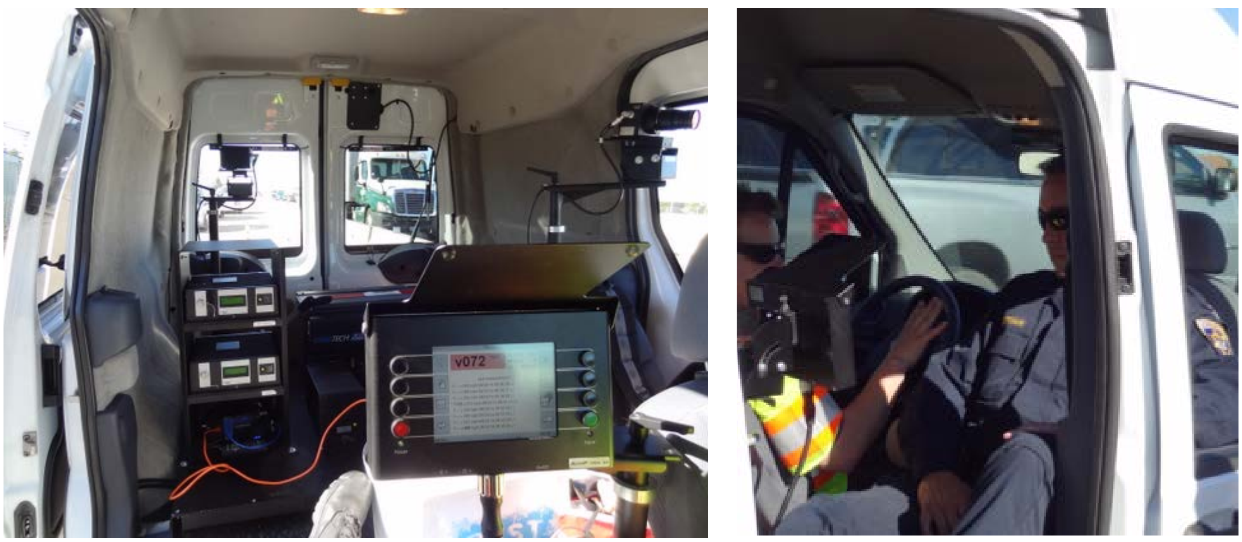

Figure 36. System with Operator in Front Passenger Seat Facing Rearward.

In the third system, the operator was seated in the front row looking forward, and all seats were in their typical configuration, as shown in Figure 37 and Figure 38. In all cases, the control interfaces were a laptop or a similar-sized control panel with a screen that would allow placement in different locations.

Figure 37. View of a PSE System From Behind Rear Seat of a Small SUV with the Operator Facing Forward.

Figure 38. View of the System Control Panel with Operator Facing Forward.

Officers did not express a preference for rearward facing seats since they are very much used to monitoring traffic while facing forward. Officers are very much concerned about monitoring the front view of the vehicle to be aware of people who have pulled over to approach the CHP vehicle. Exiting the vehicle without hindrance is another important requirement. Additionally, the view out the rear window was obstructed by PSE equipment in two out of the three cases. Per the discussion, some of the CHP vehicles do not have an optimal view through the rear window and the officers typically rely on their side mirrors.

Based on observations and discussions, configuring the system to allow the operator to work from either of the front seats seems the most practical and potentially the safest option. A single officer could operate the system while in the driver seat, and if a second person is present the control screen could be readily shared. The control screen needs to quickly swing away to allow easy egress. The operator would always be in position to immediately drive away if needed. A potential configuration that would leave all options open would be one in which the front passenger seat is rotatable, which would preclude the use of any vehicle smaller than a large van. The console area would be kept clear and the operator could easily transfer to the driving position.

Miscellaneous Functional System Requirements

Flash Requirements

Although the flash system is critical to obtaining successful images, it can potentially affect driver vision by causing flash blindness. Based on observations by officers and researchers, the flashes used in the PSE systems did not cause vision problems. There appeared to be a difference in flash power between systems, but this was not quantified and no specifications were defined. Although not observed as an issue, precautions should be used when deploying the flash systems. The vendors' technical requirements and experiences drive the flash design. Since higher flash power might solve some of the image deficiencies, future measurements and specifications may be required to limit any potential negative effects on drivers.

Historically, some countries implemented the use of black and white images illuminated with a red filtered light. This type of image is potentially of higher quality, and the red flash is much less problematic. Arizona implemented black and white imaging to improve image quality and reduce the annoyance of the flash.

Power Requirements

Per discussions with vendors, the systems are typically outfitted with batteries for four to eight hours of operation. The flash draws the majority of power and power consumption is proportional to the violation rate. The assumption is that the vehicle engine will be running and will therefore be the primary source of power.

Barrier Height

The system should be able to operate over a 40-inch barrier. The configuration represented by the Stockton test should be considered as a basic operating requirement.

Left Side/Right Side Operation

Although median operations will be less frequent, it is recommended that systems be configured to operate on both sides of the roadway shoulders.

Real-Time Operation and Remote Connectivity

Systems are not expected to be able to process the evidence in real time. Data has to be uploaded for processing at the office. Vendors do offer a remote, cell-phone-based connection for the remote support of hardware, which would be a useful feature.

Operator Interface

Most steps are automated or guided by a Graphic User Interface (GUI) to improve consistency and to reduce human error.

System Self-Checks

Self-tests are performed at least once at the beginning of deployment, maybe more during deployment. No external calibration method, such as using a tuning fork, is available or practical. Reference test signals are generated internally.

Requirements for Capturing Data on Truck-Trailer Systems

In the case of speeding tractor-trailer systems, the process of capturing proper information for the identification of the violator is more involved and can require additional processing effort. In such cases, a good image of the tractor front license plate is required since the trailers are frequently swapped, and the rear plate of the tractor is hidden behind the trailer. Capturing the front license plate was challenging in the tests performed for some of the PSE systems because flashes tend to overexpose the front license plates.

CONCLUSIONS AND RECOMMENDATIONS

The results from the field-testing indicated that exceeding the speed limits is a major problem in California highway work zones. For example, test results from the northern California test site (in the Stockton area) indicated that the number of speeding vehicles in the midnight to morning shift was in excess of approximately 500 to 1000, while, in the morning and afternoon shifts, the number of speeding vehicles exceeded approximately 1000 to 1200. Each shift consisted of 7.5 hours of testing. In southern California, the corresponding numbers ranged from approximately 700 to 2000 speeding vehicles in the midnight shift, up to 2000 in the afternoon shift, and up to 3500 in the morning shift. Considering that the sensors were not able to capture all speeding vehicles in each lane or from multiple lanes, this data shows the relatively large magnitude of the speeding problem in the work zones.

The PSE systems tested did not generate an event for every detected vehicle at or above its trigger speed. If the quality of speed-reading was not detectable, the PSE systems did not take pictures of the vehicle, even if it was traveling at or above the trigger speed. However, over approximately 60% of speeding vehicles for the lanes that were targeted were captured by the PSE systems. For a fully citable event involving a speeding vehicle, both the license plate of the vehicle and the driver had to be properly identified. Some images were not very clear and some had obstructions due to the sun visor, drivers wearing sunglasses, and so forth. Analysis of the data captured indicated that the percentages of citable events were below 50% for all PSE equipment tested. In the northern California test site, which had two traffic lanes, the percentage of citable events was estimated at approximately 30% to 50%; the data for the test site in southern California, where there were more traffic lanes, the percentage of citable events dropped to approximately 5% to 20%. CHP determined that while the PSE technology showed it had the ability to capture data, the reliability and the effectiveness of the findings does not meet the level it considers necessary for enforcement at this time.

It should also be pointed out that although the percentage of citable events were relatively low, the number of events captured in any given period of time far exceeded the numbers that currently can be handled by on-duty police officers pursuing speeding drivers at the location. For example, during the morning shift, the number of potentially citable events for the Stockton test site ranged from 23 to 52 per hour. In Los Angeles (the test site in southern California), similar numbers for the morning shift ranged from 5 to 13 per hour. Other factors which influenced the CHP's decision to not utilize PSE technology included, but are not limited to, issues associated with the judicial handling of citable events based on existing laws, the impact of the potentially much larger volume of citations upon the judicial system, and the lack of any data regarding public acceptability of the use of PSE technology for work zone speed enforcement.

The following recommendations are made based on the results of this research study:

1. Any implementation of PSE for work zones needs specific and standard protocol based on the concept of operations developed as part of this research study.

2. Any future implementation of PSE for work zones should start with a pilot study and a clear review of that study's results.

3. Methods of communication with and notification of the public in the implementation of this method of speed enforcement need to be evaluated.

4. In general, it is recommended that any future implementation of PSE technology would include periodic reviews of its overall impact; its continued implementation should be considered based on the results of those reviews, especially in terms of its impact on improved safety.

5. Due to the potential sensitivity of generated revenue, thoughtful governance on income dispersal brought in by the fines should be addressed up front.

6. The impact of PSE in work zones on the procedures and work load of the associated judicial system needs to be evaluated and considered before any implementation of the technology.

7. The relevant courts involved in the judicial handling of the citations generated need to be properly informed and provided the resources needed to manage the potential increase in the number of citations.

Special Note: The results of this research study have been shared with the California Highway Patrol (CHP). The CHP has made the following determination at this time: "while the technology showed photo speed enforcement images could be captured, the CHP does not consider the applicability of the photo speed technology as the only determining factor necessary for enforcement. Impact of photo speed enforcement on other stakeholders (e.g., Legislature, judicial council, and court systems) should be evaluated in developing a plan for future photo speed enforcement opportunities. The CHP requests to have an active role in any future photo speed enforcement opportunities."

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