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16. ABSTRACT

Caltrans contracts with CHP (California Highway Patrol) for enhanced enforcement in construction and maintenance zones under the Construction Zone Enhanced Enforcement Program (COZEEP) and the Maintenance Zone Enhanced Enforcement Program (MAZEEP). These programs provide traffic management strategies to improve project safety using supplemental CHP units to assist in the enforcement of speed restriction and provide faster incident response through the selected work zones. There is however insufficient information available to determine the degree of drivers' adherence and their level of compliance to speed reduction requirements with the use of COZEEP and MAZEEP. Furthermore, there is no quantitative data on safety benefits, best implementation configurations, and cost benefits of the COZEEP/MAZEEP programs in highway work zones. The goal of this study is to gather data and perform analysis to address the following research questions: Does the CHP presence together with Caltrans operations in work zones help achieve the safety and mobility goals? Is COZEEP/MAZEP cost effective in terms of its impact on safety? What are some of the most effective configurations in terms of the utilization of CHP officers in implementation of COZEEP/MAZEEP? Tests were performed over 10 nights in urban areas as well as two day times in rural areas that included construction as well as maintenance operations. In COZEEP tests, a condition referred to Augmented COZEEP (ACOZEEP) was also tested involving additional CHP units and ticketing of speed violators. A total of 34 tests were performed evaluating different configurations COZEEP and MAZEEP and COZEEP versus ACOZEEP effectiveness. In addition, the tests were augmented with a comprehensive survey of those who work or are involved with highway work sites as well as evaluation of 1,868 accidents that occurred with direct interactions with work zones in California from 2008-2010. The results indicate that COZEEP, MAZEEP and ACOZEEP are effective in reducing speeds in free flowing, mid-to-long distance work zones where drivers have an uninhibited field of view. Furthermore, in longer length work zones, ACOZEEP resulted in vehicles maintain their speed reduction for a longer period of time. In addition ACOZEEP resulted in additional highway safety improvements in identifications of DUI (Driving Under the Influence) drivers. Furthermore, the results also provide data on some of the most effectiveness configurations in terms of location of Police units in the work zone and best practices as well as clear cost and safety benefits in reduction of fatalities and reduction of injury severity due to reduced traffic speeds as a result of COZEEP/MAZEEP.

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Advanced Highway Maintenance and Construction Technology Research Center
Department of Mechanical and Aerospace Engineering
University of California at Davis

Scientific Evaluations of Operational Performance, Procedures, Impacts, and Benefits of Highway Construction Zone Enhanced Enforcement Program (COZEEP) and the Highway Maintenance Zone Enhanced Enforcement Program (MAZEEP)

Final Report

Bahram Ravani, Principal Investigator
and
Chao Wang, Patricia Fyhrie, Wilderich A. White, and Andrew T. Malone

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Final Report of Contract: 65A0418, Task ID: 2249

October 28, 2013

California Department of Transportation

LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
ACOZEEP	Augmented Construction Zone Enhanced Enforcement Program
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
Caltrans	California Department of Transportation
CHP	California Highway Patrol
COZEEP	Construction Zone Enhanced Enforcement Program
DRISI	Caltrans Division of Research, Innovation, and System Information
ECOZEEP	Enhanced Construction Zone Enhanced Enforcement Program
LED	Light Emitting Diode
LIDAR	Light Detection and Ranging
LLC	Limited Liability Corporation
MAZEEP	Maintenance Zone Enhanced Enforcement Program
MPH	Miles per Hour
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
No.	Number
OEM	Original Equipment Manufacturer
PC	Personal Computer
PDO	Property Damage Only
RTMS	Remote Traffic Microwave Sensor
vs	versus

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4. INTRODUCTION

Traffic on California highways has been observed to exceed the posted speed limit in construction and maintenance work zones. These elevated speeds increase the risk of injury and death to workers and vehicle occupants as well as cause property damage. To reduce these travel speeds and potential for traffic accidents within a work zone, in selected locations, the California Department of Transportation (Caltrans) currently employs the California Highway Patrol (CHP) to enforce the posted work zone speed limits using COZEEP (Construction Zone Enhanced Enforcement Program) and MAZEEP (Maintenance Zone Enhanced Enforcement Program). Previous studies from other states and nationally have indicated a prevalent opinion on the benefits of the speed enforcement through use of additional officers (similar to COZEEP and MAZEEP) at the work zone. Use of radar and police officer speed enforcement in work zones has become prevalent in many states in recent years. In California alone, Caltrans presently spends approximately $28.3 million for COZEEP and $7.1 million for MAZEEP annually and the cost of such operations are only increasing. The goal of using COZEEP/MAZEEP is to reduce traffic speeds to the posted speed limits. CHP officers may also be used to slow down or assist in stopping or directing traffic to enable necessary breaks in traffic for critical movements of the construction or maintenance equipment and operations. The operation is expected to reduce the number of speeding drivers and it is assumed to improve the safety and reduce number and or severity of accidents in work zones. There have however been no scientific studies of the cost and safety benefits of such operations nor has there been a proper assessment of best practices and optimal configurations in utilization of COZEEP/MAZEEP or CHP officers in work zones.

Studies have been conducted by other States such as in Kentucky [1] and Minnesota [2] which have indicated that police officer presence in work zones can result in significant speed reductions in the traveling motorist. Speed reductions have also been observed with photo radar programs (see. for example, [3-5]). In fact many States have passed legislation to allow use of photo radar speed enforcement in work zones. A recent study [6] has shown that photo radar enforcement reduces speeding by up to approximately 27%. Hajbabaei [7] studied the effects of four different methods of speed management that involved using speed trailer, police presence, photo radar and various combinations of these methods. The study showed that all such methods resulted in speed reductions in the work zone. None of the studies mentioned however have made any attempt of correlating such speed reductions to safety improvements and reduction in accidents or injury severity in work zones. Furthermore, there is no study performing a proper cost benefit analysis of any such techniques or an evaluation of best practices and optimal configurations for utilization of such techniques.

In addition much of the existing work has been based on surveys or at most on very limited testing. The existing surveys are also not conducted in California taking into account all the key personnel involved in COZEEP/MAZEEP operations. Chapter 2 of the Construction Manual [8] discusses some of the risk factors that can indicate the need for COZEEP. The decision to use COZEEP is made by the Project Engineer early in the project development phase. In addition, the CHP operating policies are taken into account. In the case of MAZEEP, the Maintenance Area Superintendent makes the assessment for the need and the Maintenance Supervisor makes

the request for MAZEEP services (see, [9] for more details). All these indicate that surveys of Project Engineers, Maintenance Area Superintendent, Maintenance Supervisor and work zone working crew involved in COZEEP or MAZEEP speed enforcement and can provide important data related to benefits and best practices of such operations.

This research is focused on evaluation of COZEEP/MAZEEP operation and not Photo radar speed enforcement for speed reduction and safety and other benefits in highway work zones. The study has involved both comprehensive testing as well as a survey of the key personnel working in highway work zones in California. The comprehensive testing has involved a total of 34 tests (the actual number of tests were 35 but the results of one test was not included in the analysis due to special conditions present at the work zone for that particular test) that were conducted including both urban as well as rural areas in California. In addition a comprehensive blind survey was developed by the research team and was conducted by Caltrans collecting data from key personnel involved in work zone operations. CHP officers did not participate in the survey.

The results of this study provide data and analysis that would allow responses to at least the following questions:

- The degree of drivers' adherence and their level of compliance that could be attributed to the implementation of CHP presence and the overall enforcement operation.
- A better understanding of the relationship of the CHP enforcement together with Caltrans operations to the safety and mobility goals of Caltrans.
- The cost and safety benefits of COZEEP and MAZEEP.
- Identification of some of the most effective configurations in terms of the utilization of CHP officers in implementation of COZEEP/MAZEEP?

5. APPROACH

This research used a multimodal approach consisting of actual testing and data collection at highway work zones in both COZEEP and MAZEEP operations combined with conducting a comprehensive survey of work zone practitioners. In addition computer simulations and reconstruction of a large number of actual work zone collisions were performed as part of the analysis of the results of this study. The results were used to develop a better understanding of the parameters that could improve the effectiveness and cost benefits of these operations while improving mobility and safety in highway work zones.

Tests were performed in highway work zones at twelve different dates including urban (San Diego area) and rural areas (Redding and Weed) in California. In these tests, the speed of traffic was measured using iCones at different locations in the approach as well as within the highway work zone under conditions with and without police presence and in the case of some of the tests there was enforcement and ticketing. The testing in the urban areas spanned over eight nights in construction work zones and included testing a total of 17 different conditions. These included a condition referred to as Augmented or Enhanced COZEEP (ACOZEEP). This condition

involved regular COZEEP configuration with additional CHP units used for enforcement and ticketing of speeding drivers. During COZEEP operations using only one CHP unit in the work zone, the officer normally does not leave the work zone except when observing serious violations. In ACOZEEP there are additional CHP units that can pursue violators. Testing in rural areas spanned over a period of four days and included both COZEEP as well as MAZEEP conditions. A total of thirteen different conditions were tested in rural areas.

A test layout was designed to capture speed of traveling public at different locations near or within the work zone while having minimal impact on highway infrastructure as well as driver attention while allowing for rapid deployment and tear down of the sensing system at a highway work zone.

All tests involved measurements of speed of traveling public using iCones. The following conditions were tested:

1. COZEEP Conditions (12 tests)
2. ACOZEEP Conditions (13 tests)
3. MAZEEP Conditions (9 tests)

In all the tests, the following speeds were also measured:

4. Speeds Upstream of the Closure for reference on location dependent travel speed.
5. Speeds throughout work zone with no CHP to evaluate the effect of closure alone on speed.

In order to supplement information gathered in the testing a detailed survey questionnaire was prepared by the research team. The survey was conducted by Caltrans and data was collected from those who work or are involved with highway work sites. The survey was provided through an external web site, in a blind fashion, and it could be filled out by workers using a smart phone or other mobile devices with internet access. The survey could also be printed and filled out manually and submitted. A total of 529 responses were collected in a six week period with 60% to 65% of responses being from highway workers. The responses fairly represented all area with highways within California. A plot of responses from different Caltrans districts is depicted in Figure 1.

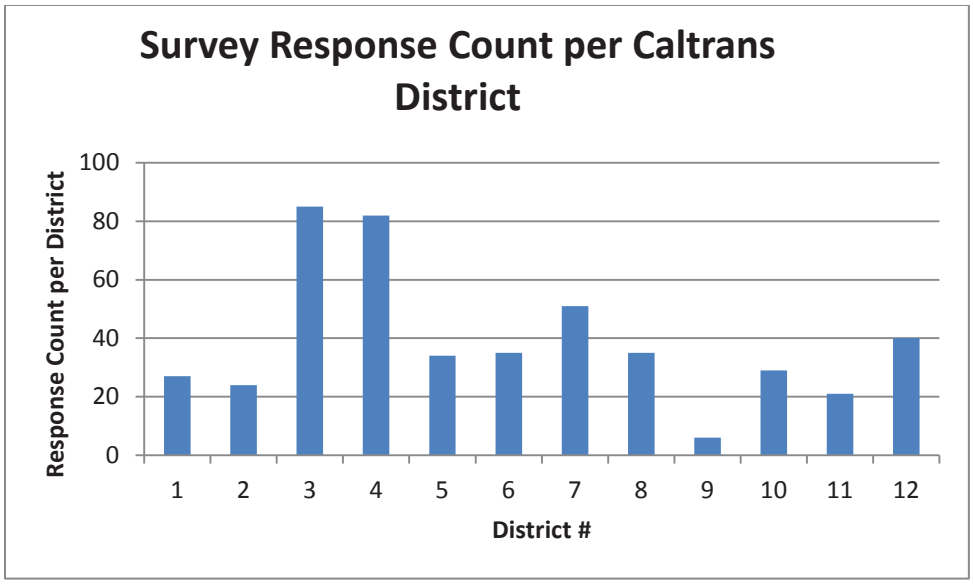


Figure 1. Survey Response Count by Caltrans Districts.

The chart in Figure 1 indicates that the survey was effective in soliciting responses well across California. The data in the survey responses provided valuable information on highway workers views on safety benefits of COZEEP/MAZEEP and some of the best operational configurations for COZEEP/MAZEEP implementation.

A proper assessment of the cost benefits of COZEEP/MAZEEP operations that would be quantitative and would provide an assessment of the level of the benefits achieved is very difficult and requires much detailed data. In order to provide estimates of such cost benefits, CHP traffic accident reports for a period of three years from 2008 to 2010 was collected for all accidents in California that the accident occurred in or near a highway work zone. A total of 13,125 CHP reports were identified and reviewed. These reports were studied with redacted identification data to ensure confidentiality of personal information. A total of 1,868 of these accidents were identified that had direct interactions with the work zone active area. These accidents consisted of 347 accidents that involved intrusions into the work zone and 1,521 non-intrusion work zone accidents. The distribution of these accidents in terms of fatalities, non-fatal injury accidents, and Property Damage Only (PDO) accidents for each set is shown in the pie charts depicted in Figure 2 (167 involved injuries and 136 only had property damage). From the remaining 1,403 non-intrusion accidents, a total of 469 resulted in injuries and the rest only involved property damage to the traveling public. The distribution of work zone accidents for each type is depicted in Figure 2.

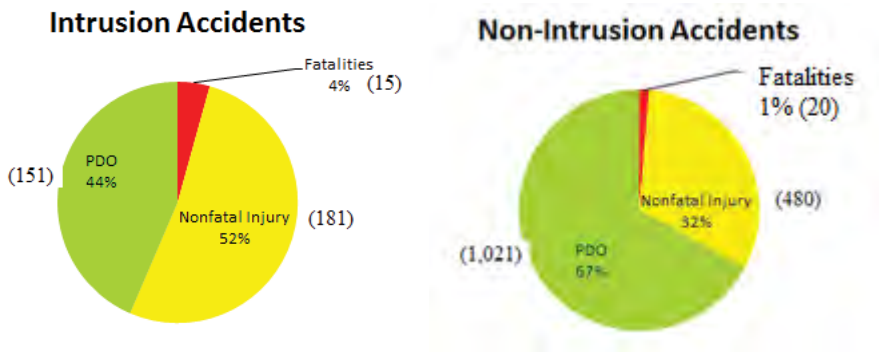


Figure 2. Work Zone Accident Distribution by Type for Intrusion and Non-intrusion Accidents.

The cost of these accidents were then calculated considering the cost of property damage as well as injury and fatality costs using standard cost data for Caltrans. The cost data used for such calculations is summarized in Table 1. The actual costs of these collisions are discussed in the next section.

Accident Outcome	Cost
Accident involving a Fatality	$5.8 Million
Non-fatal Injury Accident	$67,400
Property Damage Only Accident	$10,200

Table 1. Cost Data for Injuries, Fatalities, and Property Damage Only.

A sub-set of all these accidents were then selected that had consistent and sufficient data for reconstruction and simulation. These included 90 intrusion accidents and 50 injury and fatality accidents having direct interactions with the work zone. These two sets of accidents were reconstructed using PC-Crash accident reconstruction software and simulated to evaluate the impact of COZEEP/MAZEEP and the resulting cost and safety benefits. The results are discussed at the end of the next section.

3. TESTING METHOD AND PROCEDURE

Objective

In evaluating the effectiveness of COZEEP/MAZEEP, the main objective of speed testing was to measure the effect of these operations on traffic speed. Since the establishment of a lane closure and its signage may cause the traffic to slow down, an “incremental speed reduction” is investigated to highlight the effects on traffic speed as a result of COZEEP/MAZEEP

deployment. The incremental speed reduction is defined as the difference in traffic speeds measured during No CHP condition and COZEEP/ACOZEEP or MAZEEP conditions. In the No CHP condition, the work zone was protected with a standard lane closure as defined by Chapter 8 of Caltrans Maintenance Manual, without any CHP presence. In COZEEP/ACOZEEP or MAZEEP conditions, CHP vehicles were utilized to enhance the safety of the work crew as instructed by the local Resident Engineer in charge of the work zone.

The 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 has indicated that they can provide consistent estimates of average traffic speed if used appropriately. In addition, the iCones are the only measurement system at the researcher's disposal that allows for rapid and non-intrusive deployment for work zone data collection.

Test Locations

The use of COZEEP/MAZEEP was evaluated in both urban (San Diego) and rural (Redding and Weed) work zones in California. A total of 12 test-days of COZEEP/MAZEEP were accumulated during the study. Out of these 12 test days, 8 were performed during night time in urban areas, 2 were performed during night time in rural areas and the remaining 2 were performed during day time in rural areas. A test-day is a typical work day where the researchers instrumented the highway for testing during a Caltrans construction or maintenance function with COZEEP/MAZEEP support. During these 12 days of testing, a total of 12 tests were conducted for COZEEP, 13 tests were conducted for ACOZEEP and 9 tests were conducted for MAZEEP.

In the urban area, the two different types of use of CHP support used are COZEEP and ACOZEEP. In the COZEEP operation one CHP vehicle was typically parked at a location upstream of the work crew. The main function of the CHP presence was to alert the traveling public of the work zone ahead and to calm the traffic before it reaches the work crew. Active enforcement of traffic violation was rare since it requires the CHP vehicle to leave its post and renders the work zone unprotected. ACOZEEP operations were similar to COZEEP but had additional CHP vehicles participating in the operation. In this case, the additional CHP vehicle can engage in pursuit of vehicles violating traffic while the other CHP vehicle can remain in its post upstream of the work crew. Note that in COZEEP, the single CHP vehicle still occasionally stops offending vehicles when severe cases of traffic law violations were observed. During the 8 test-days in urban areas, 8 tests were performed for COZEEP and 13 tests were performed for ACOZEEP. However, the test data from the 4th and 8th test-days were not used in analysis due to missing No CHP condition on test-day 4 and unusually low speeds caused by traffic congestions on test-day 8.

In rural areas, both COZEEP and MAZEEP operations were tested. The first set of two test-days was in Redding in northern California and the work was performed during maintenance work zones. A total of 4 tests were conducted for the MAZEEP condition. The second set of two test-days took place in Weed, again in northern California, in construction work zones. A total of 4 tests were conducted for COZEEP during the first day of testing in Weed. During the second

day, the iCones were arranged to simulate a typical maintenance work zone and a total of 5 MAZEEP tests were conducted during the second test-day in Weed.

Urban Environment Test Method

For the urban environment tests, the researchers had a total of eleven iCones available for deployment. Nine were placed along the closure side of the freeway and the remaining two were placed on the opposite side to provide a duplication of speed readings as a check on accuracy. One of the two iCones on the opposite side was placed across the first of the nine and the other one was placed across from the one closest to the active work area. This layout was used for a typical lane closure for all of the testing done in the urban area. An illustration of the lane closure including its signage and the iCones used in the testing is shown in Figure 3 below.

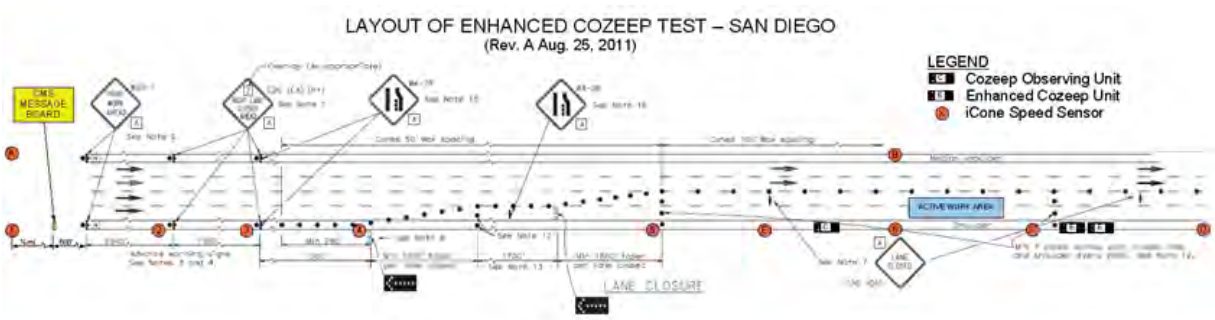


Figure 3. The Test Layout for Testing in Urban Areas.

The nine iCones along the closure side of the highway were located to capture speed readings as traffic passed through the closure. The first five iCones were intended to capture the speeds through the advance warning area and the taper up to the point at which the lanes are fully closed. iCone number 6 is assigned to a position immediately upstream of the active work area which is the point at which drivers will ideally have responded to all the indications that workers are present and will be traveling at the speed limit. The remaining three iCones are then located in the closed lanes to capture the transitions in speed throughout the work zone.

In a lane closure, the Advance Warning Area starts at the first signage and lasts up to the first "arrow-board" which is where the taper begins. The closures usually begin with a portable Changeable Message Sign (CMS), located about 1 mile ahead, indicating that a lane closure is in place. The intended function of each iCone is described below:

- iCone number 1 is intended to define the baseline traffic speed in which drivers are not aware of the upcoming closure. It is placed up to a mile ahead of the CMS sign. This is an idealized location in that traffic may be entering and exiting and therefore changing speeds between this point and the closure. The actual position of this iCone is determined by the researcher when they arrive at the site. The idea is to place the iCone where it monitors free flowing traffic approaching the work zone.

- iCones number 2 and 3 are located next to the two 'Right (or Left) Lanes Closed Ahead' signs that will potentially cause drivers to begin to reduce speed and move out of the lanes being closed. These are the first signs that indicate to the driver that a specific action is required in addition to monitoring speed.

- iCone number 4 is located at the first "Arrow-board" which is the point at which the taper begins. It is the beginning of the closure and in previous testing a majority of cars at this point had moved out of the lane being closed. All the locations indicated are referenced to this 'zero' point along the closure.

- iCone number 5 is located at the end of the taper at the Lane Closed sign. This iCone captures the speed at the beginning of the buffer area before the active work area.

- iCone number 6 is located immediately upstream of the active work area. This iCone captures the speed of traffic that is closest to the work crew. Since all iCones were placed at the beginning of the work day, its distance to the work crew may vary for a moving work zone.

- iCone A and B were placed across the highway opposite of iCone number 1 and number 6, respectively. They provide a redundant set of speed measurement at these two locations.

- iCone C, D, and E were used to monitor speed throughout the work zone, with iCone D measuring the speed as vehicles leave the work zone.

The actual layouts during the field tests slightly varied at times from the planned configuration for various logistic and safety reasons particular to the site and the time of the test on location. For safety and logistical reasons and to maximize data integrity, the iCones were not moved once placed.

Test Procedure in Urban Areas

The urban area tests were performed in San Diego, CA. All tests were performed during night time construction operations. The typical procedure for each test began with a meeting in the evening at the local Resident Engineer's office, where a Caltrans staff would brief the researchers on the details of the work being done that night. During this time the traffic control contractor would begin placing the lane closure, usually starting with the advance warning area signage and the arrow boards. After the permitted time for closing the lanes, traffic control cones were placed at the work area forming a taper followed by the rest of the lane closure. After that the iCones were placed inside of the lane closure side by the researchers. For the iCones on the opposite side, the researchers typically place them before the lane closure was in place with the escort of an attenuator truck and sometimes one of the COZEEP/ACOZEEP CHP officers. During each these tests, there were three CHP vehicles with 2 officers per vehicles supporting the road work. The researchers would have a meeting with the CHP officers and resident engineer representatives at the staging area and discuss test objectives, plan, sequence and time

duration of test conditions, as well as methods of communications. It is at this time the researchers described the concept of ACOZEEP and consult with the officers for details on various options of implementation, such as the preferred location of additional CHP vehicles and whether the additional vehicles should turn on their flashing lights. The researchers also passed out CHP Log Sheets to officers and asked them to record the time and GPS coordinates of their locations as they park in the work zone and when making stops for enforcement activities. These log sheets are retrieved from the CHP officers by the end of a test day, which is typically around 3:00 to 4:00 AM.

In addition to the average speed data collected by the 11 iCones, the researchers also intermittently drove past the section of the highway where the work was taking place, and took notes on observations. The researchers also recorded video as well as still images of the work zone during these passes. The video recording later proved extremely helpful in reconstructing the test environment for post processing of test data.

Rural Areas Test Method

For the testing in rural areas, the researchers had a total of six iCones available for deployment, and all of them were placed along the closure side of the freeway. The layout used for a typical lane closure and its signage used in the testing is shown in Figure 4.

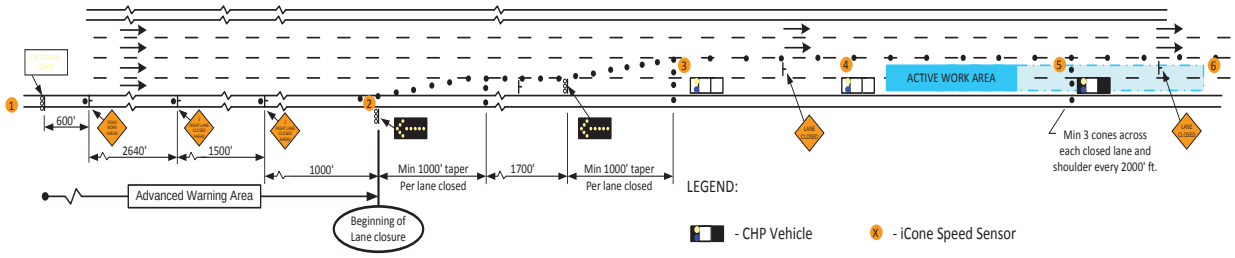


Figure 4. The Test Layout for Testing in Rural Areas.

All six iCones along the closure were located to capture speed readings as traffic passed through the closure. The first three iCones are intended to capture the speeds through the advance warning area and the taper up to the point at which the lanes are fully closed. iCone number 4 is assigned to a position immediately upstream of the active work area which is the point at which drivers will ideally have responded to all the indications that workers are present and will be traveling at the speed limit. Together with iCone number 5 and 6, the last three iCones were evenly distributed throughout the active work area until the end of the lane closure. The intended function of each iCone is described below:

- iCone number 1 is intended to define the baseline traffic speed where drivers are not aware of the upcoming closure. It is placed at approximately 0.5 mile upstream from the first indication of the lane closure. If the condition upstream does not reasonably

represent the baseline condition, such as existence of intersections or ramps, this iCone is placed at first sign of the closure.

- iCone number 2 is located at the beginning of taper near the arrow board to capture any speed reduction due to the signage prior to taper.

- iCone number 3 is located at the end of taper to capture the speed due to closure of lanes prior to the work area.

- iCone number 4, 5 and 6 are evenly distributed to capture the speeds in the vicinity of workers through the test period. The intention was to cover the span of the active work area until the end of the lane closure with these iCones.

The actual layouts during the field tests slightly varied at times from the planned configuration for various logistic and safety reasons for the test site. For safety and logistical reasons and to maximize data integrity, the iCones were not moved once placed unless absolutely necessary. For the second test day in Weed, CA, the iCones 4 through 6 were placed 1000 feet downstream of iCone 3 and were 1000 feet apart from each other, simulating the effect of MAZEEP on a short (4000 feet) work zone.

Rural Area Test Procedure

The tests in Redding were performed during two consecutive night time maintenance activities. The researchers had meetings with the maintenance crew and the supporting CHP officers at the local Caltrans yard each evening before the activity. The maintenance crew showed the details of the task being performed and discussed the iCone placement layout with the researchers. The researchers then met with the CHP officers and distributed the CHP Log Sheet similar to the ones used in the tests done in San Diego. The maintenance crew then proceeded with placing traffic control cones to form the lane closure, and the iCones were placed after the lane closure was set up according to the deployment layout mentioned above.

During these tests, there were two CHP vehicles with 2 officers per vehicles supporting the road work. There were works being done on both direction of the roadway at the same time and the CHP officers were supporting both work zones, and rolling traffic breaks were required at various times by the maintenance crew. The researchers decided to not interfere with the officer's original plan of MAZEEP deployment due to unfamiliar circumstances of the tasks performed by CHP. The time duration of each test condition were later extracted from the video footage taken by driving through the work zone making frequency passes. Conditions such as NO CHP and MAZEEP were established based on observation of CHP location and time, which was verbally noted in the video footage. Due to lack of precise knowledge on CHP location, only a small portion of the test data from Redding was used in the analysis.

The tests in Weed were performed during two consecutive day time construction activities. The researchers had meetings with a representative from the local Resident Engineer's office each

morning before the work began. During the first segment of the meetings the researchers were briefed on the location and details on the work performed. The second segment of the meeting was moved to the work site where they were joined by CHP officers and discussed details of the test conditions. There was one CHP vehicle with one officer supporting each day of the testing.

During the tests in Weed the researchers had an opportunity to give instructions to the officer on where to park the CHP vehicle. Consequently, the researchers proceeded to investigate the effect of CHP location on traffic speed. Working with the CHP officer, two locations were established for the CHP vehicle: upstream near the first signage of the work zone, and at the end of taper. The CHP vehicle was parked outside of the shoulder of the road at both locations as shown in Figure 5. The CHP Log Sheet was handed to the officer to record the time and location after each time the vehicle has moved.

Similar to the urban area tests, the researchers again made observations and recorded videos along with verbal notes as they as they drove past the work zone on the highway. The video footage helped confirming the CHP location recorded on the CHP Log Sheet, and helped reconstructing the events during the test. A summary of the notes can be found in the speed profile plates.

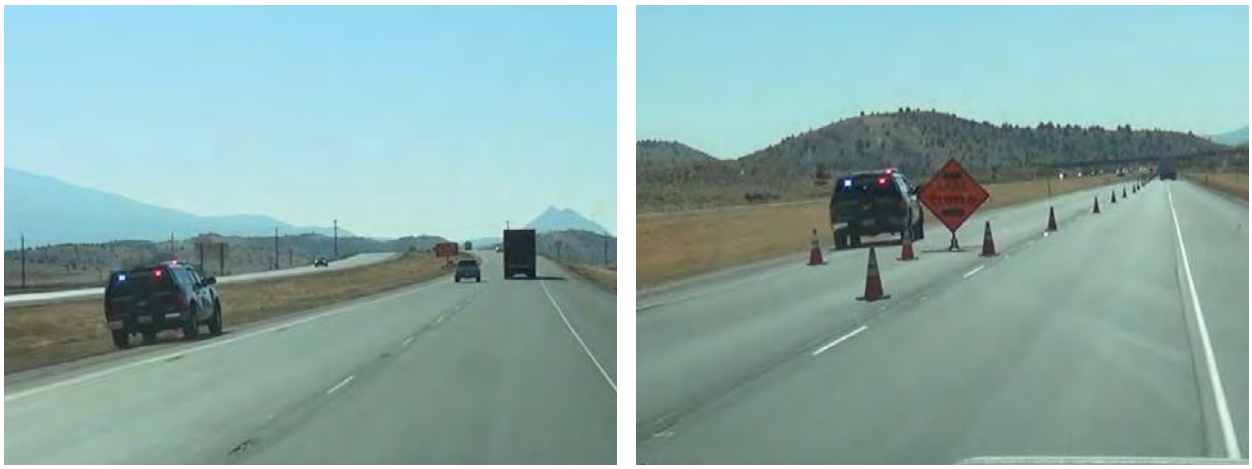


Figure 5. Locations of CHP vehicles: at the Beginning of Taper (left) and at the End of Taper (right).

4. PRACTITIONER SURVEY

To supplement the information gathered from testing, it was felt that the opinions of the construction/maintenance road crews are significant and should be collected. The personnel working alongside the traveling public undoubtedly have a pertinent assessment of COZEEP and MAZEEP effectiveness. The survey was designed and analyzed by the researchers and conducted by Caltrans. This section describes the design of the survey, the responses gathered, and subsequent analysis of the responses.

Survey Design

The survey was designed to solicit the opinions of road work personnel on the effectiveness of the COZEEP and MAZEEP programs. The goal was to collect pertinent and accurate data from those who spend most or all of their working time at the work site. Both Caltrans and contract personnel were targeted to provide their assessments by completing the survey. Collecting the opinions from CHP officers was considered but was not performed due to a conflict with CHP guidelines in participation in such surveys.

To get a broad representation of all types of road work being done in the state of California, all work crews in all twelve Caltrans districts (see Figure 6) were asked to complete the survey on a voluntary basis. The survey was designed to be focused and sufficiently brief to accommodate the busy schedules of the potential respondents. Anonymity was considered to be important to the survey takers so identifying information was excluded purposefully from the survey questions.

Figure 6. Map of Caltrans Districts.

Ease of access was also considered a critical component of the survey in order to obtain a complete spectrum of experiences. A third party software company was used to ensure easy access and completion of the survey ("SurveyMonkey" [10]). The survey was made accessible via an external website where it could be "filled out" by workers through a smartphone or other mobile devices with 3G or mobile internet connection. If internet access was not available, the survey could be printed out and completed manually.

Availability of the survey came via a private webpage created by "SurveyMonkey". A link to this webpage was sent by Caltrans personnel through email to the targeted road work crew personnel only and it is assumed only members of that targeted audience completed the survey. To encourage a high percentage of the targeted audience to complete the survey, Caltrans personnel, sent out several emails providing the link to the survey with words of encouragement to complete the survey. These emails were sent out three times in the course of the survey collection period.

More information on the questions in the survey is discussed in the remaining of this section. The actual survey is provided in Appendix A.

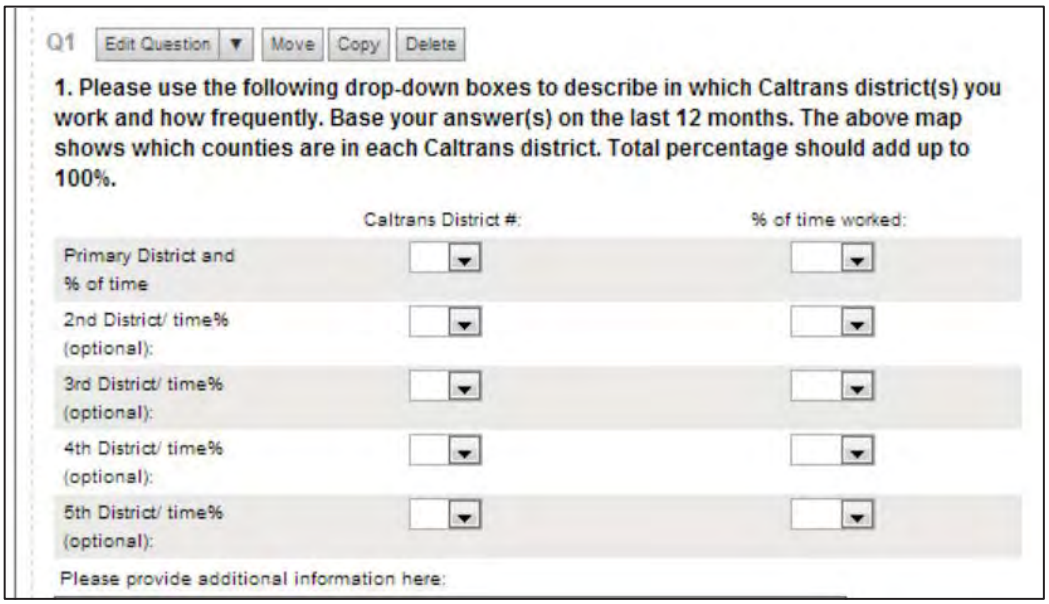
Survey Introduction

The survey was designed with an introductory paragraph that was geared to orient and introduce the responder to the survey completion process. A brief explanation of the survey, assurance of anonymity, and miscellaneous instructions were also included in the introduction. The introduction is restated below:

> "We need your opinion on how to improve work zone safety. Specifically, what are your thoughts on having CHP vehicles visibly present at a work zone? For example, do you think having COZEEP (CHP at a construction site) or MAZEEP (CHP at a maintenance work site) improves safety in general? If so, how does it improve safety and under what conditions?
>
> All of you who see first-hand how traffic responds when CHP is present have the most valuable knowledge. This survey is intended to capture this knowledge and your experiences. We look forward to reading and gathering everyone's opinions.
>
> Your participation, whether it is complete or partial, is completely voluntary and anonymous. We will not be recording your identity or any identifying information. We only wish to collect your opinions in an effort to improve the safety of highway work zones.
>
> Many thanks for your time and cooperation!"

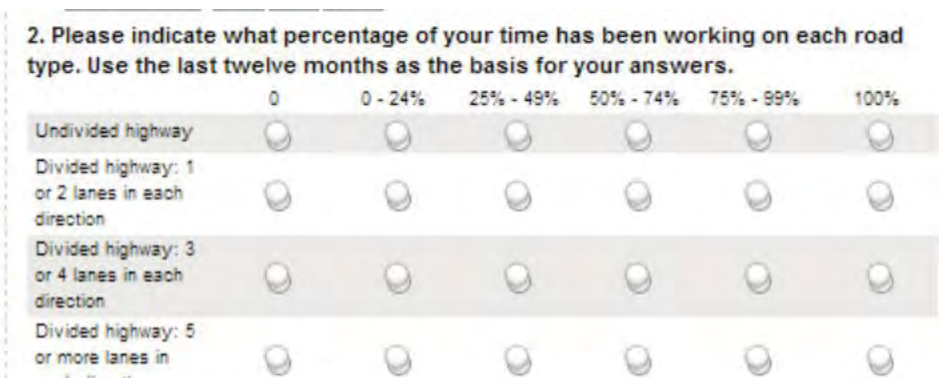
Question 1

The first question inquires which Caltrans district(s) the responder has worked in. To ensure anonymity we specifically did not ask whether the individual worked for Caltrans or for a contracting firm. A depiction of question one as it appeared in the computerized survey is shown below:



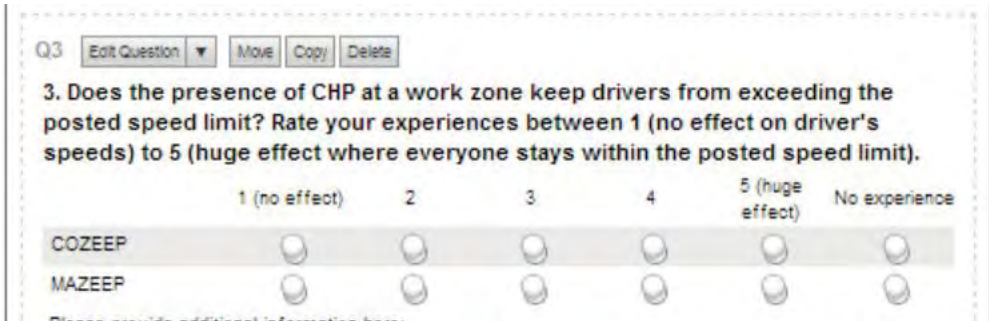
Question 2

An important aspect of deploying COZEEP or MAZEEP is the road size (number of lanes) and whether it is a divided or undivided highway. Specifically, the distribution of survey respondents working on the type of the road category was needed. The survey respondents were asked whether they work on undivided highways (choice 1), divided freeways with 1 or 2 lanes (choice 2), divided freeways with 3 or 4 lanes (choice 3), or divided freeways with 5 or more lanes (choice 4). For each highway category the individual selects what percentage of their time is dedicated to each type. The time choices are broken down into quarters. A depiction of this question as it appeared in the computerized survey is shown below:



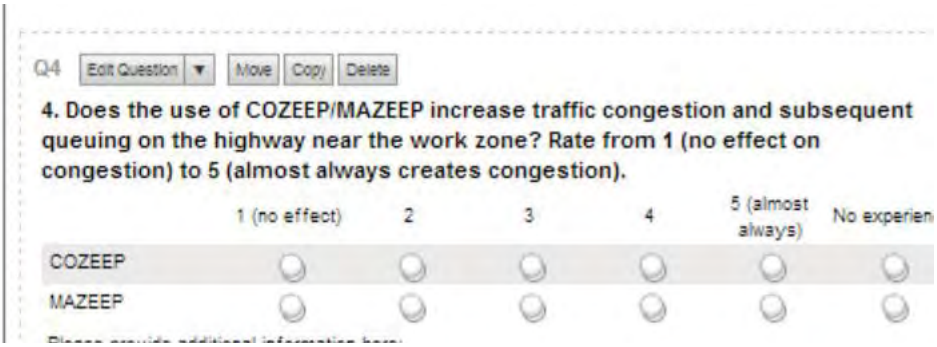
Question 3

The third question of the survey asked the practitioners how traveling speeds are affected by the presence of CHP units at a work site. Although it is known that speed cannot be precisely estimated by a pedestrian (worker in this case) without use of specialized equipment, the estimation of speed changes was still considered meaningful. The workers can also estimate how traffic speeds feel with and without COZEEP or MAZEEP present. Answers were to be given on a scale of 1 to 5 with “1 = No effect on driver’s speeds” to “5 = Huge effect; all drivers stay within speed limit”. There is a button for “No experience” If that applies. The survey respondents were also given the opportunity to provide input on both COZEEP and/or MAZEEP. A depiction of this question as it appeared in the computerized survey is shown below:



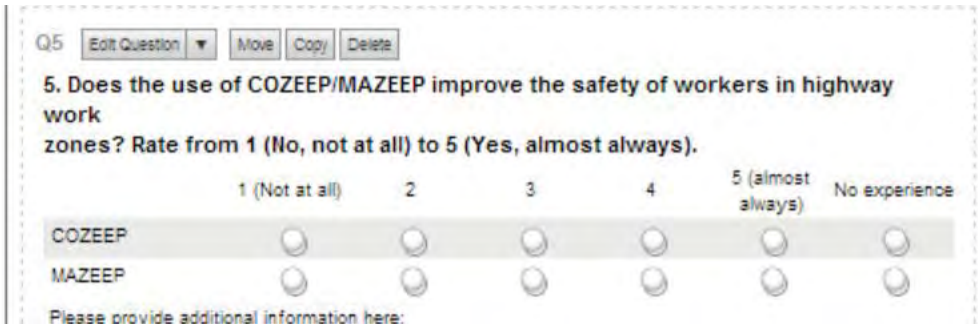
Question 4

The fourth question was asked to provide feedback on traffic congestion. This question was intended to address a concern raised by some people indicat8ing that the presence of CHP will increase traffic congestion and generate longer queues. The respondents were asked to provide their opinions on changes in traffic throughput. A scale of 1 to 5 was used again with "1 = has no effect on traffic congestion" to "5 = Almost always increases traffic congestion" Input was sought for both COZEEP and MAZEEP. A depiction of this question as it appeared in the computerized survey is shown below:



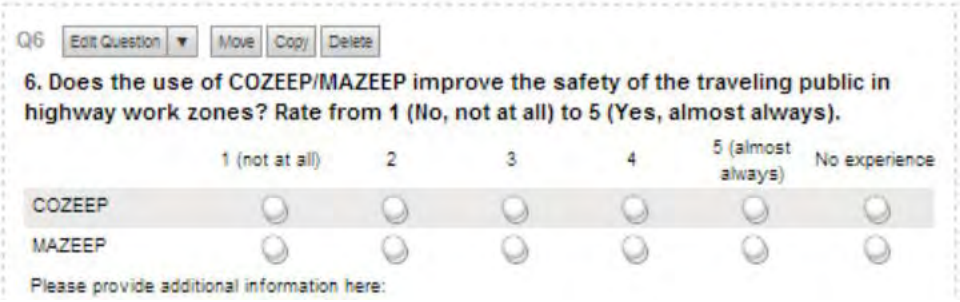
Question 5

The fifth question of the survey was intended to determine the effect of CHP presence on personal safety of the workers as perceived by the respondents. The respondents were asked to scale their personal safety benefits using a range of 1 to 5 where"1" means that having CHP on board offers no additional safety to 5 indicating that having at least 1 CHP unit present always increases their personal safety. The format of this question was similar to that of question s 3 and 4 previously. A depiction of this question as it appeared in the computerized survey is shown below:



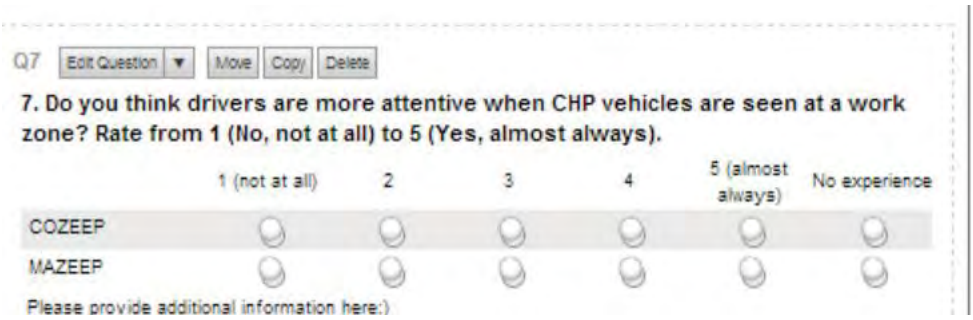
Question 6

In question number 5, the survey inquires about the safety of the workers themselves. In this question, we ask for their opinions on the safety of the traveling public. The format is very similar to the previous question – just the perspective is different. A depiction of this question as it appeared in the computerized survey is shown below:



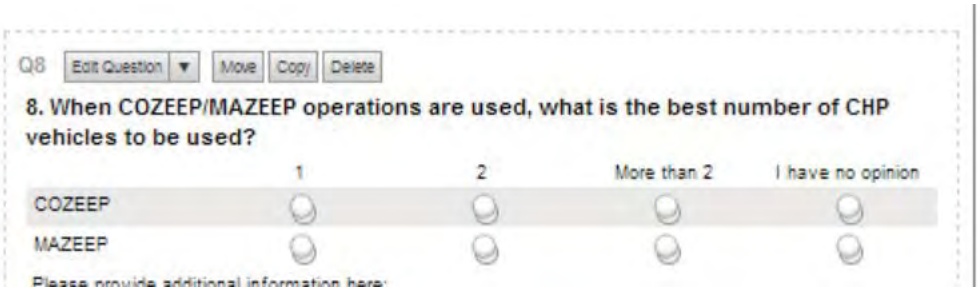
Question 7

This question was intended to obtain feedback on the effect of CHP presence at the work site on driver behavior specifically on driver attentiveness. Attentive drivers are assumed to be not eating, using their cell phones and keeping their eyes on the road. A depiction of this question as it appeared in the computerized survey is shown below:



Question 8

This question was intended to obtain the respondents view point on the number of CHP units at a work site for optimum safety benefits. This question was depicted in general terms with no specifications associated with the work site such as length, location or immediate environment. A depiction of this question as it appeared in the computerized survey is shown below:



Question 9

The next piece of information that was sought was on the positioning of the CHP units at a work site. Caltrans nomenclature on the various positions within a work site was used [11]. Figure 7 depicts a sample layout of a work zone with a one-lane closure. Question 9 is the survey's first question on positioning of CHP units. It is assumed for this question that there is only one lane closed on the roadway.

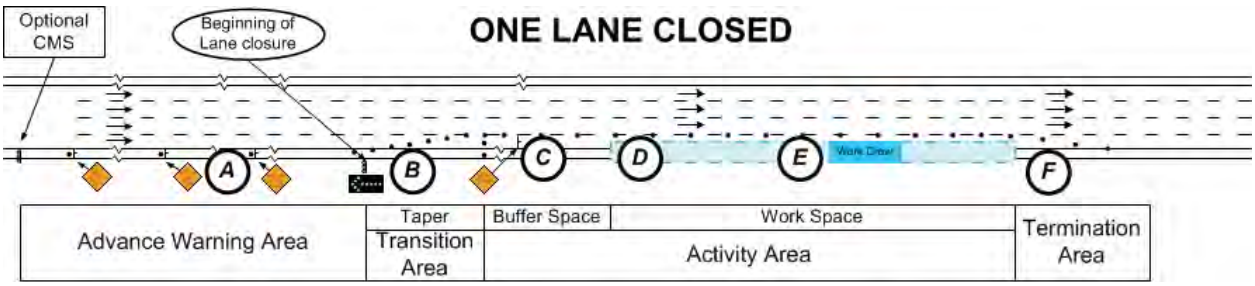
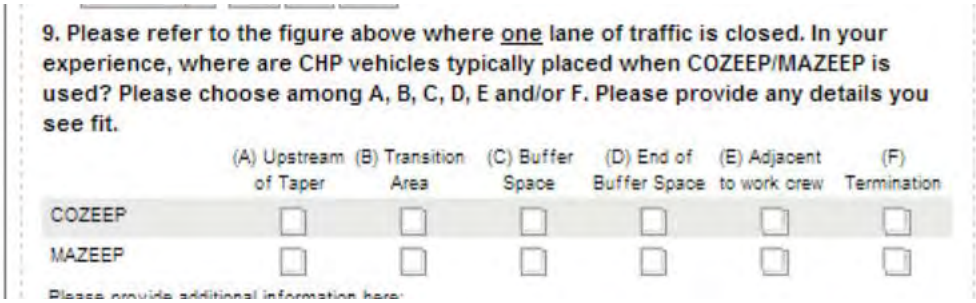


Figure 7. A Sample Work Zone Layout with one lane Closure.

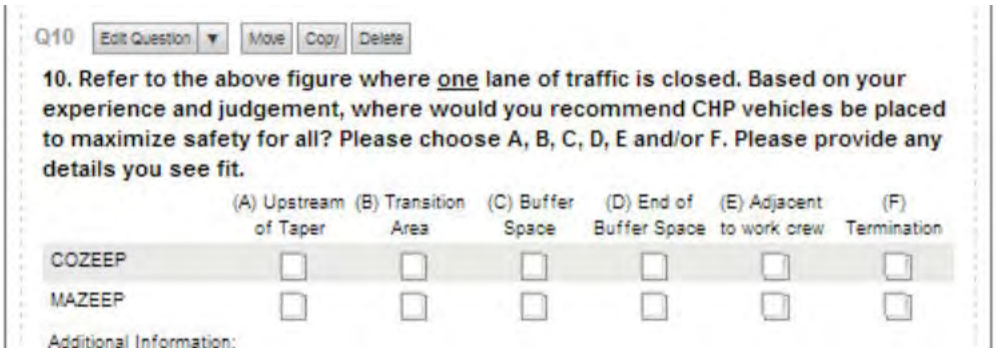
A depiction of this question as it appeared in the computerized survey is shown below:



It is important to note that question 9 asks for the "typical" or "current practice" positioning of CHP vehicles. The next question is intended to obtain the opinions of the respondents on where they think is best for the CHP vehicles to be positioned, not necessarily what is in practice today.

Question 10

In the previous question, the respondents are asked where CHP vehicles are typically placed in a work zone. This question asks for their opinion on where they think would the best location for positioning the CHP vehicles at the work site. Again, it is assumed that there is a one-lane closure. A depiction of this question as it appeared in the computerized survey is shown below:



Question 11

This and next questions are similar to the previous two questions except that, in these, it is assumed that there is a two-lane closure. The purpose of these questions is to identify whether there is a difference in desired positioning of CHP unit when the number of lanes closed is different.

Figure 8 depicts a sample highway work zone with 2 (or more) lanes closed. This and the next question are related to this figure.

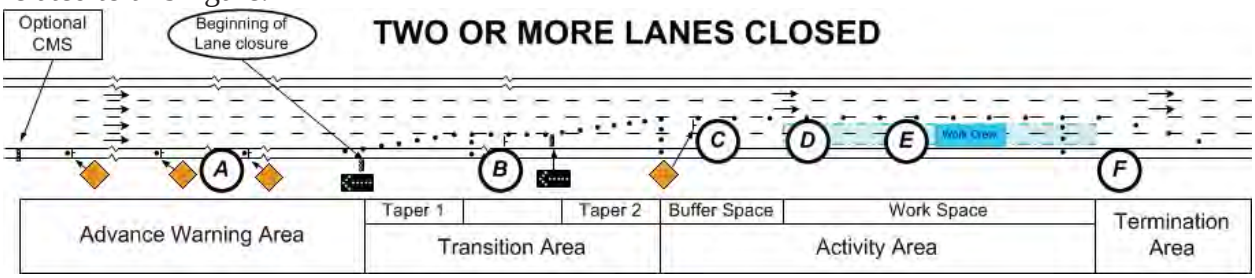
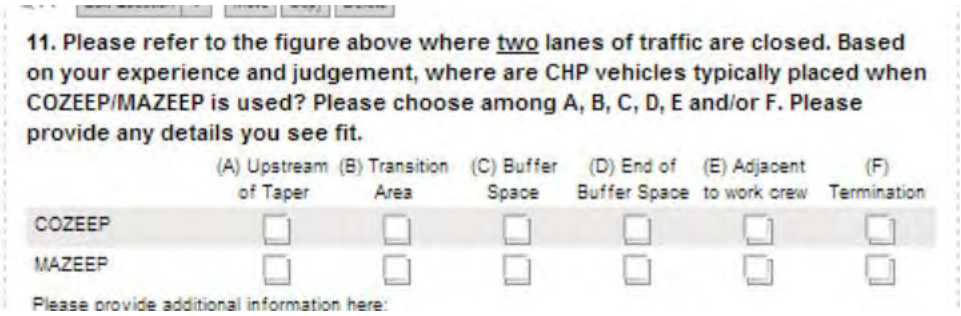


Figure 8. A Sample Work Zone Layout with two-lane Closure

A depiction of this question as it appeared in the computerized survey is shown below:

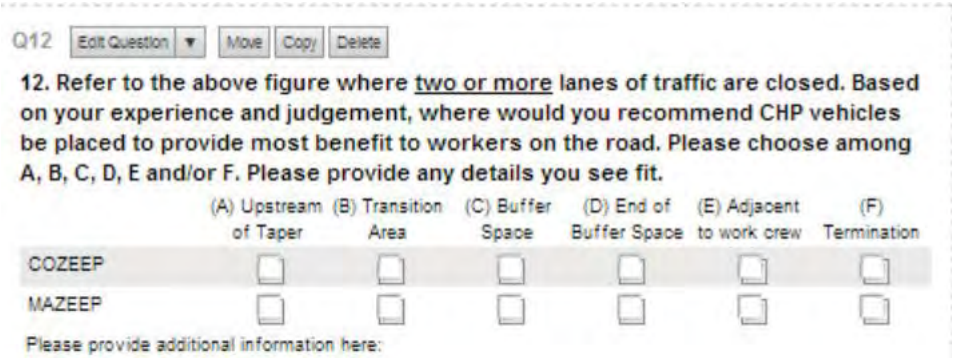


Please note that here the respondents are being asked for the typical or current practice in terms of the positioning of the CHP vehicles in a 2 lane closed work site.

Question 12

This question is the last of the four questions dealing with the positioning of the CHP unit in a work site. It differs with the previous question in that it is asking for the opinions of the respondents on the best location

for positioning of the CHP unit rather than the typical practice. A depiction of this question as it appeared in the computerized survey is shown below:


Q12 Edit Question ▼ Move Copy Delete

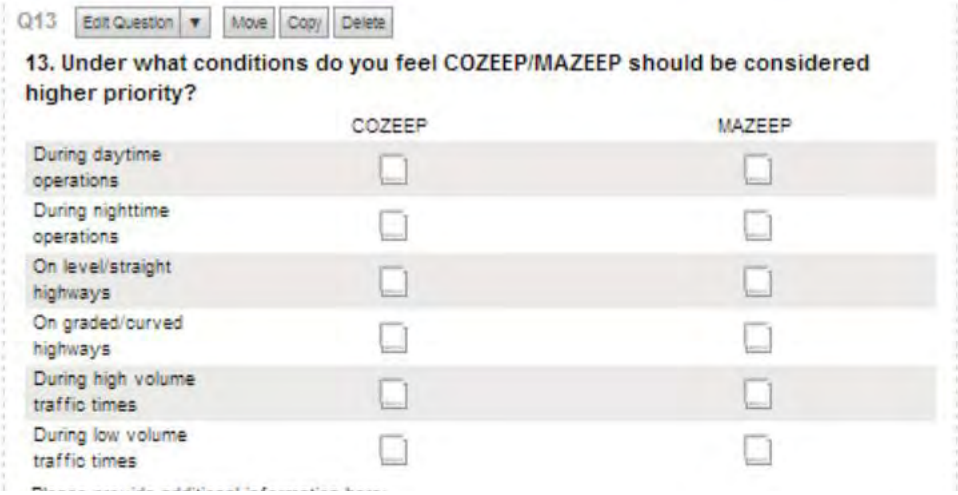
12. Refer to the above figure where two or more lanes of traffic are closed. Based on your experience and judgement, where would you recommend CHP vehicles be placed to provide most benefit to workers on the road. Please choose among A, B, C, D, E and/or F. Please provide any details you see fit.

	(A) Upstream of Taper	(B) Transition Area	(C) Buffer Space	(D) End of Buffer Space	(E) Adjacent to work crew	(F) Termination
COZEEP	☐	☐	☐	☐	☐	☐
MAZEEP	☐	☐	☐	☐	☐	☐

Please provide additional information here:

Question 13

This question focuses on the environment conditions that can best be suitable for utilization of COZEEP/MAZEEP in a work zone. A depiction of this question as it appeared in the computerized survey is shown below:


Q13 Edit Question ▼ Move Copy Delete

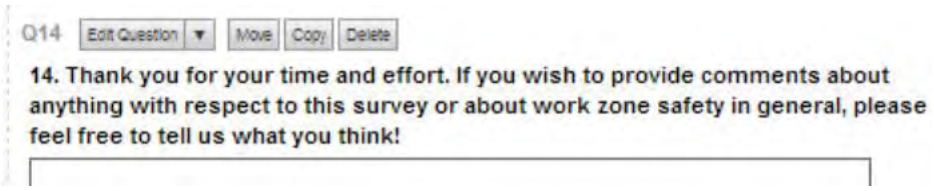
13. Under what conditions do you feel COZEEP/MAZEEP should be considered higher priority?

	COZEEP	MAZEEP
During daytime operations	☐	☐
During nighttime operations	☐	☐
On level/straight highways	☐	☐
On graded/curved highways	☐	☐
During high volume traffic times	☐	☐
During low volume traffic times	☐	☐

Please note that the survey taker may indicate more than one selection.

Question 14

This question was intended to thank the respondents and provide them an opportunity to provide comments or their views related to work zone safety on any matters not covered in the survey. A depiction of this question as it appeared in the computerized survey is shown below:

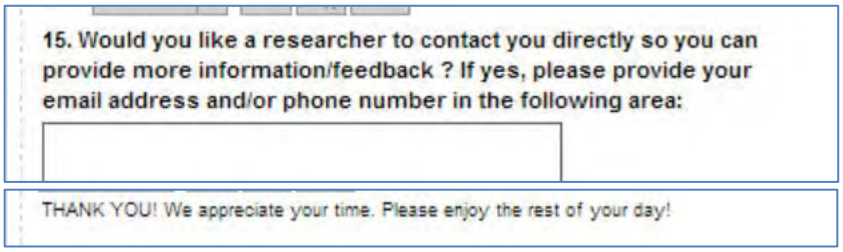

Q14 Edit Question ▼ Move Copy Delete

14. Thank you for your time and effort. If you wish to provide comments about anything with respect to this survey or about work zone safety in general, please feel free to tell us what you think!

Please note that space was allocated with almost every survey question so that the respondents would have ample opportunity to provide additional comments. This question was intended to provide additional encouragement for detailed input.

Question 15

This last question was intended to give the respondents an opportunity to be contacted by a researcher if they had a desire for such a contact and a more detailed discussion of their input. A depiction of this question as it appeared in the computerized survey is shown below:



Cost Benefit Analysis

In the NCHRP report [11], a method based on using Bayesian statistics is described for performing cost benefit analysis of highway work zones. This method, however, requires the use of a safety performance f8unction for each highway under consideration which is difficult to obtain and properly quantify. These functions estimate the collision frequency per year-mile which is hard to quantify for each highway under construction and or maintenance. Furthermore, the method does not properly address the level of benefits received from utilizing CHP officers in the work zone or proper consideration of cost of injuries and fatalities that can be potentially prevented by using such measures. In this study, therefore a different methodology is therefore used for evaluating the cost benefits of COZEEP/MAZEEP in work zones. The methodology used is as follows:

- A sample period of three years (2008 to 2010) was selected for which all Police Traffic Collision Reports for all Accidents in California that occurred in or near a highway work zone was collected.
- These were studied and a subset of them that had sufficient data for accident reconstruction was selected.
- Using the accident reconstruction software PC-Crash, these accidents were reconstructed determining the vehicle speed s and trajectories.
- Using standard 1.5 seconds of cognition/reaction time for the drivers involved, PC-Crash reconstructions were used to determine the location of the vehicle in its pre-accident trajectory where the driver starts to perceive the condition resulting in the accident.
- The PC-Crash software was then used as a simulation tool to evaluate the effect of speed reductions due to COZEEP/MAZEEP from this location of the vehicle to evaluate the accident and injury outcomes due to the speed reduction. Three levels of speed reductions were considered: 3 MPH, 5 MPH and 7 MPH.

The distribution of the Police Traffic Collision Reports in terms of the numbers involving intrusions into the work zone and those resulting in fatalities and injuries are detailed in Table 2. Out of these reports those that had enough detailed data for accident reconstruction using the PC-Crash software were selected. The distribution of the accidents and the selection of those for reconstruction are summarized in Table 3. In terms of intrusion accidents 90 accidents were selected and in the case of injury accidents (whether intrusion or non-intrusion), 56 accidents were selected that had sufficient and consistent data for analysis and reconstruction.

Accident Data Collected	Number Reports
Total Number of Reports Reviewed for Reconstruction	13,125
Total Number of Reports Directly Interacting with the Work Zone	1,868
Total Number of WZ Intrusions	347
Total Number of Injury and Fatal Reports	696 (35 fatalities)
Total Number of Non-Injury Reports	1,172

Table 2. The Distribution of Police Traffic Collision Reports Evaluated.

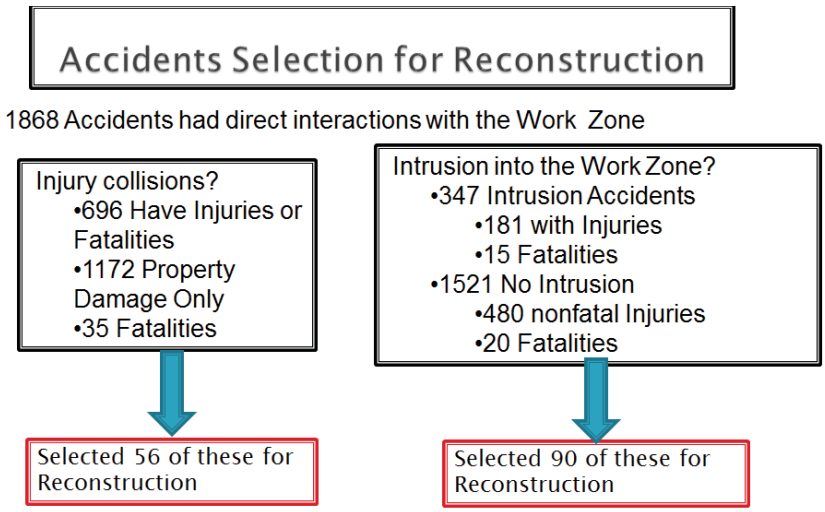


Table 3. No. of Accidents Selected for Accident Reconstruction.

5. RESULTS, CONCLUSIONS, AND LIMITATIONS

Test Results and Conclusions

The detailed data for each test indicating the location and the date of each test as well as the nature of the lane closure together with plots of average traffic speeds at different iCone locations together with a Google Earth ™ image of the site are given in Appendix B. A typical speed data for one of the tests is depicted in Figure 9. As it can be seen from this figure, although there is clear speed reduction due to use of COZEEP and ECOZEEP, the difference in speed reduction between the two is only significant in that vehicles maintained their reduced speeds over a longer distance in ECOZEEP as compared to COZEEP. This suggests that ECOZEEP is more effective for longer length work zones.

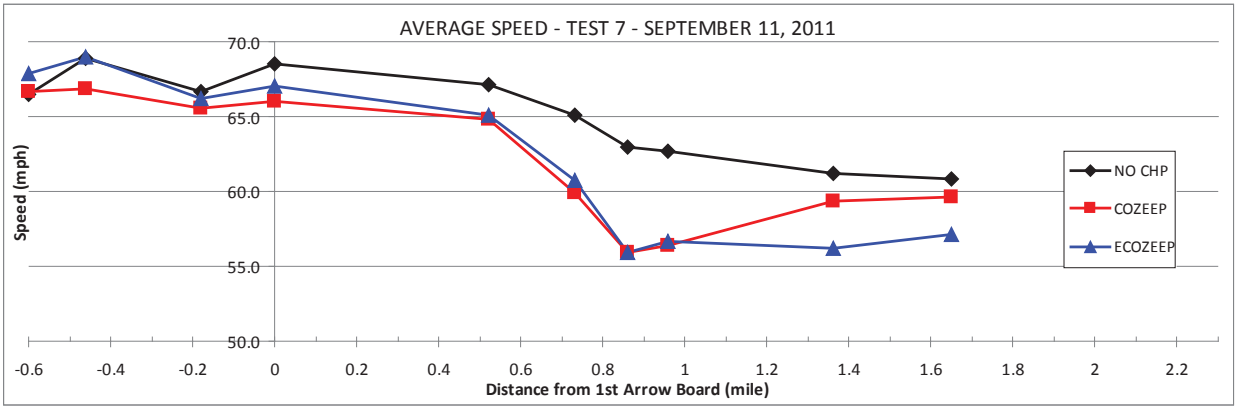


Figure 9. A Sample peed Data for a Test.

As it can be seen in the plots in Figure 9, the speed of traffic at different locations within the highway work zone varies. Therefore, in order to properly discuss speed reduction due to use of COZEEP/MAZEEP, one has to choose an appropriate reference location within the work zone. In this study, two reference locations are selected for discussing speed comparisons. In addition, the maximum speed reduction observed at any locations within the work zone is also discussed. The two reference locations are the end of taper and the end of buffer area as shown in the diagram in Figure 11. This figure depicts a typical highway work zone in California. The location of maximum speed reduction varied in different tests conducted and consisted of locations varying from the beginning of taper to some point in the active work area.

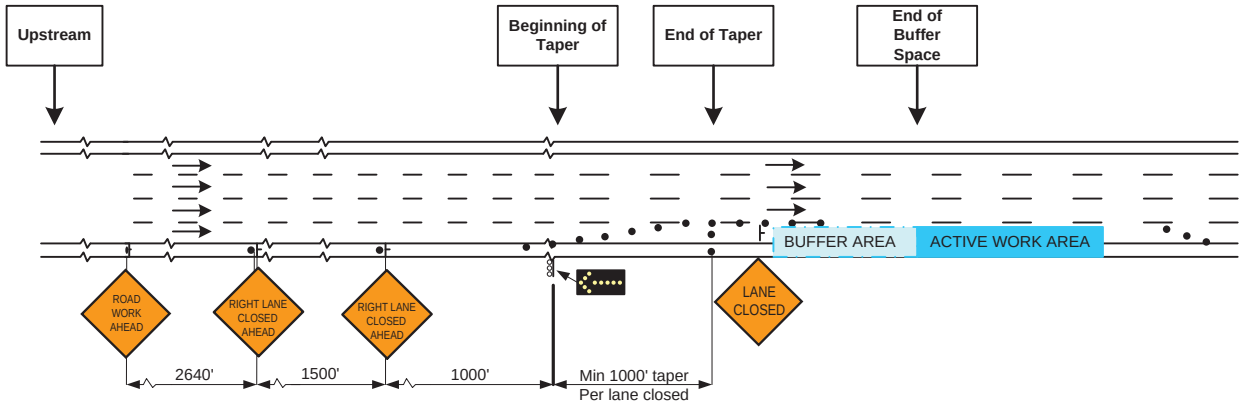


Figure 10. Definition of Reference Locations in a Highway Work Zone.

In the series of tests conducted in urban as well as rural areas, average traffic speeds were measured using iCones at several locations within the work zones under conditions with no CHP presence (no COZEEP/MAZEEP conditions) and with COZEEP/MAZEEP conditions. Comparing the tests data at each reference location provides an indication of speed reduction at such locations as a result of COZEEP/MAZEEP operations. The range of speed reductions for different speed limits within the work zone as observed in the tests conducted is summarized in
Table 4. The data in this table reflects the speed reduction over and above any reductions due to the lane closure alone. In other words, the speed reductions listed in this table, are incremental reductions when CHP was present (COZEEP or MAZEEP conditions) as compared to what was observed at the same locations within the work zones without CHP presence and only due to the lane closure. It should be noted that the location of the largest incremental speed reduction varied among the tests and occurred at different locations in the work zones tested varying from the beginning of taper to some point in the active work area.

Incremental Speed Reductions (Due to COZEEP/MAZEEP)									
	End of Taper			End of Buffer			At The Location of Largest Reduction		
Speed Limit	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
55 MPH	3.3	6.9	0.2	2.6	6.4	-0.1	4.3	6.9	1.4
65 MPH	3.0	5.2	0.4	3.5	6.6	2.0	4.8	7.0	3.5
70 MPH*	3.8	7.6	1.2	4.4	7.4	1.7	12.4	20.8	5.6

Table 4. Incremental Speed Reduction Due to COZEEP/MAZEEP as Compared to When There was no CHP Present. Note: *Not including the 2nd night of Redding tests ("CHP end of taper" and "rolling traffic break" conditions) due to absence of "No CHP" condition.

The incremental speed reduction values listed in 4 are with respect to and above the values observed as a result of signage and closure alone without any CHP presence.

The following conclusions are derived from the data in Table 4:

- In urban areas (urban freeway, 65 MPH speed limit), deployment of COZEEP resulted in an average incremental speed reduction of 3.0 MPH and up to a maximum reduction of approximately 5.2 MPH (range of 0.4 to 5.2 MPH) at the end of taper and an average incremental average speed reduction of 3.5 MPH and up to a maximum reduction of 6.6 MPH (range of 2.0 to 6.6 MPH) at the end of the buffer area. At the location where the incremental speed reduction was largest throughout the work zone, the incremental speed reduction was an average of 4.8 MPH and up to a maximum of 7 MPH (range of 3.5 to 7.0 MPH).

- In rural areas (rural freeway, when speed limit was reduced from 70 MPH and posted at 55 MPH), deployment of MAZEEP/COZEEP (first day of the testing involved COZEEP and the second day of the testing involved MAZEEP type conditions: shorter work zones) resulted in an average incremental speed reduction of 3.3 MPH and up to a maximum of 6.9 MPH (range 0.2 to 6.9 MPH) at the end of taper and an average incremental speed reduction of 2.6 MPH and up to a maximum of 6.4 MPH (range of -0.1 to 6.4 MPH) at the end of the buffer area. At the location where the incremental speed reduction was largest throughout the work zone, the incremental speed reduction was an average of 4.3 MPH and up to a maximum of 6.9 MPH (range of 1.4 to 6.9 MPH).

- In rural areas (rural freeway, speed limit 70 MPH, NOT including rolling traffic break), deployment of MAZEEP resulted in an incremental speed reduction of average of 3.8 MPH and up to a maximum of 7.6 MPH (range 1.2 to 7.6 MPH) at the end of taper and an incremental speed reduction of an average of 4.4 MPH and up to a maximum of 7.4 MPH (range of 1.7 to 7.4 MPH) at the end of the buffer area.

- At the location where the incremental speed reduction was largest throughout the work zone, there was rolling traffic break. In this location, the incremental speed reduction was an average of 12.4 MPH and up to a maximum of 20.8 MPH (range of 5.6 to 20.8 MPH). In this test, the CHP vehicle in addition to providing rolling traffic break, it was also shadowing the maintenance vehicle. Such events may have larger impact on traffic flow than a typical MAZEEP operation where the CHP vehicle is at a stationary location outside of the traveling lanes. Another potential cause for the slow traffic speed observed in Redding is the narrowed traveling lane. Due to the nature of the maintenance work being done, traffic control cones were placed beyond the lane markers of the closed lane. As a result, the lane width of the traveling lane was reduced. ***The data in this test was therefore excluded for consideration with other test data.***

- The maximum speed reduction observed at the end of buffer was consistently higher as compared to the speed reduction observed at the end of taper. This could have been due to the localized effect of the location of the CHP vehicle being closer to the end of taper under the test conditions.

  In the tests that were performed in the urban San Diego area, a condition referred here to as ACOZEEP (Augmented COZEEP) was also tested. This condition involved using extra CHP vehicle units for pursuing and ticketing speeding vehicles. The range of speed reductions for the same test locations performed with COZEEP alone in urban San Diego area are summarized in Table 3.

Incremental Speed Reductions (Due to ACOZEEP)									
	End of Taper			End of Buffer			At The Location of Largest Reduction		
Speed Limit	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
65 MPH	3.8	8.2	0.7	4.6	6.4	2.6	6.0	8.2	2.6

Table 5: Incremental Speed Reduction Due to ACOZEEP as compared to when there was no CHP present. (Notes: *ACOZEEP is only tested in San Diego, urban freeway with speed limit of 65 MPH.)

The following conclusions are derived from the data in this table:

- For the same urban freeway, signage, and lane closure with a speed limit of 65 MPH as in the case of the COZEEP tests, when additional CHP units with enforcement and ticketing of speed violators (ACOZEEP) were added, the incremental speed reduction was an average of 3.8 MPH and up to 8.2 MPH (range of 0.7 to 8.2 MPH) at the end of taper and an average of 4.6 MPH and up to 6.4 MPH (range of 2.6 to 6.4 MPH) at the end of the buffer area. At the location where the incremental speed reduction was largest throughout the work zone, the incremental speed reduction was an average of 6.0 MPH and up to 8.2 MPH (range of 2.6 to 8.2 MPH).

- It is clear from the above data that ACOZEEP slightly increased the incremental speed reduction from an average of 3 MPH to 3.8 MPH and up to a maximum reduction from 5.2 to 8.2 MPH for the same work zone conditions and speed limit (speed limit of 65 MPH).

The following conclusions are derived from actual observations at the testing sites combined with the collected data:

- COZEEP/MAZEEP operations are effective in reducing speeds in free flowing, mid- to long-distance work zones where drivers have an uninhibited field of view.

- In the longer length work zones, ACOZEEP resulted in vehicles maintaining their speed reductions for a longer distance as compared to COZEEP.

- In ACOZEEP configurations for the eight test sets in urban freeways, enforcement data collected throughout the study from the California Highway Patrol (CHP) officers (deployed at the work zone sites) resulted in the following data for all the eight test sets combined:
    - At least nine verbal warnings for speeding
    - Nine citations for speeding
    - Two Driving Under the Influence (DUI) arrests
    - Nine undefined stops (most likely for speeding).

- ACOZEEP enforcement data (collected at night time) indicates identification and reduction of DUIs on the highway which in general is expected to improve highway safety.

Data collected at the actual work zones was also used to evaluate the degree of traffic compliance with the posted speed limits in the work zones. The results are summarized in Table 6. The data in this table indicate the percentage of vehicles going above three speed thresholds. The speed thresholds considered are the posted speed limit for the work zone, 5 MPH above the posted speed limit, and 10 MPH above

the posted speed limit for the work zone. A measure of the degree of traffic compliance with the posted speed limit can be obtained by looking at percentage drop from these thresholds when COZEEP/MAZEEP or ACOZEEP are used as compared to the data for standard closure with no CHP presence.

The following conclusions are derived from the data in this table:

- Test data indicates that in both urban and rural areas there is a clear drop in the average percentage of vehicles going above the speed limit when COZEEP/MAZEEP operations are used.

- In the urban areas, test data indicates that COZEEP operations resulted in a drop of 14% (40%-26%=14%) in the average number of vehicles going above the speed limit.

Percentage of Vehicles Traveling At or Above Speed Threshold										
	Speed Threshold*	Standard Closure			Closure + COZEEP/MAZEEP			Closure + ACOZEEP		
		Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Urban	Speed Limit	40%	57%	26%	26%	50%	9%	24%	34%	9%
Urban	Speed Limit + 5 MPH	18%	30%	7%	9%	27%	1%	7%	14%	0%
Urban	Speed Limit + 10 MPH	5%	11%	0%	3%	10%	0%	2%	4%	0%
Rural (Redding)	Speed Limit	8%	8%	8%	2%	5%	0%	N/A		
Rural (Redding)	Speed Limit + 5 MPH	1%	1%	1%	0%	0%	0%			
Rural (Redding)	Speed Limit + 10 MPH	0%	0%	0%	0%	0%	0%			
Rural (Weed)	Speed Limit	51%	61%	45%	28%	45%	13%	N/A		
Rural (Weed)	Speed Limit + 5 MPH	17%	21%	15%	5%	10%	1%			
Rural (Weed)	Speed Limit + 10 MPH	6%	9%	4%	1%	3%	0%			

Table 6. Data on Degree of Traffic Compliance with the Posted Speed Limits. Note: Speed Limits: Urban - 65 MPH, Rural (Redding) - 70 MPH, Rural (Weed) - 55 MPH, reduced from 70 MPH due to the work zone.

- In urban areas when ACOZEEP was used there was an additional 2% drop in the average percentage of traffic going above the speed limit.

- In the rural areas the percentage reduction in the average number of vehicles going above the speed varied from 6% in the Redding test to 23% in the Weed test. These tests involved both COZEEP as well as MAZEEP type conditions.

Practitioner Survey Results and Conclusions

The practitioner survey captured data from construction and maintenance crew in terms of their field experiences, observations, and perceptions.

The following conclusions are derived from the responses:

- **On Speed Reduction and Safety Benefits:**
  - 78% of COZEEP workers who responded and 82% of MAZEEP workers who responded indicated that CHP presence had a very large effect on drivers adhering to the posted speed limits.
  - 84% of COZEEP respondents and 92% of MAZEEP respondents indicated that CHP presence improved worker safety.
  - 72% of COZEEP respondents and 81% of MAZEEP respondents indicated that presence of CHP improved public safety.
  - 88% of COZEEP responders and 82% of MAZEEP respondents indicated that the CHP presence improved driver attentiveness.
  - 88% of COZEEP respondents and 94% of MAZEEP respondents indicated that driver attentiveness was increased when COZEEP and MAZEEP operations were used in a work zone.
  - 62% of COZEEP respondents and 60% of MAZEEP respondents indicated that COZEEP/MAZEP operations had no effect on **traffic congestion** in the work zone.

- **On Implementation and Most Effective Configuration**
  - In terms of identifying the conditions when it is most effective to utilize COZEEP/MAZEEP, the respondents indicated “Nighttime” conditions as the highest priority with “High Traffic Volume” and “Curved/Graded Roads” as the next priority.
  - In terms of the location for the CHP units in the work zone, for both one and two lane closures, the higher percentage of the respondents recommended the placement of the CHP units in a safe area in the “Buffer Space”.
  - In terms of the preferred number of CHP units, a larger percentage of the respondents recommended use of two CHP units instead of one unit for both COZEEP as well as MAZEEP operations.

Conclusions From the Cost Benefit Analysis

The total costs due to injuries, fatalities, and property damage only for accident having direct interaction with the work zones in California for the three-year period considered (a total of 1,868 accidents) were calculated using the cost basis discussed earlier in Table 1. The results are summarized in Table 7.

Total number	Associated Cost Accident	Cost for all 3 years	Average Cost Per Year
35 Fatalities	$5.8 Millions	$203 Millions	$67.7 Millions
661 Non-fatal Injury collisions	$67,400	$44.55 Millions	$14.85 Millions
1172 PDO collisions	$10,200	$11.95 Millions	$3.98 Millions
	total:	$259.5 Millions	$86.5 Millions

Table 7. Accidents Involving Direct Interactions with a Work Zone - 3 year period.

The following conclusions are derived from the data in Table 7:

- The average yearly cost of accidents that have direct interactions with the work zone can be approximately $86.5 Million per year. This includes the cost of such accidents to the traveling public combined with those of the highway workers (note: the same cost basis is used for both the traveling public and highway workers for consistency purposes).

- The average cost of fatalities (considering both the traveling public as well as highway workers) alone can be approximately $67.7 Million per year. It should be pointed out, however, that there may be no cost value that can replace the life of a person but in order to have a way of comparing the impact of a fatality, some standard cost (in this case based on Caltrans data) is used.

- The average cost of non-fatal injuries (considering both injuries to traveling public as well as highway workers) can be approximately $14.8 Million a year and the cost of property damage alone can be approximately $3.98 Million per year.

Assessing the quantitative effect of the level of the benefits of COZEEP/MAZEEP on reducing costs of injuries and fatalities in highway work zone accidents is very difficult. However, to obtain some indication of the level of such benefits is determined here by using the following methodology utilizing the accident reconstruction software PC-Crash:

a. Reconstructing the accidents using PC-Crash to understand parameters such as collision severity, trajectory, and timing of driver reactions as well as the factors leading to the cause of the accident.

b. Simulating the same accidents using PC-Crash but this time reducing the speed of the vehicle in the work zone by the incremental reductions when COZEEP/MAZEEP is utilized as observed in the test data discussed earlier.

c. Evaluating the injury severity potential and outcome in the simulated accidents and comparing them to that of the actual accidents to determine the level of reduction (if any) in injury or fatalities due to incremental speed reductions observed when using COZEEP/MAZEEP operations.

Out of all the accidents considered, 696 involved fatalities or injuries. However data on details of injuries did not exist in all the CHP reports. Furthermore, even for cases were data on injuries was included in the CHP reports, only injuries such as broken bones, damage to internal organs, and skull

fractures were noted. Data on soft tissue injuries or other types of injuries were not available for evaluation limiting the results of this analysis. Since injury accidents can typically also involve soft tissue injuries, the analysis presented is presumably more conservative.

There was another factor that also limited the number of accidents that could be reconstructed. Not all CHP reports had enough data on accident parameters that the accident could be fully reconstructed. For example, all accidents involving roll overs had to be excluded due to lack of detailed data for proper accident reconstruction. Since such accidents typically involved injuries, the results presented are even more conservative.

A total of only 56 out of the 696 accidents analyzed had enough data on injuries, fatalities, and important accident parameters that could be reconstructed for evaluation of injury outcome due to incremental speed reduction as expected from COZEEP/MAZEEP operations. Since the test data as discussed earlier showed average incremental speed reduction of approximately 3 MPH to maximum speed reductions of approximately 5 to 7 MPH (using round numbers) in COZEEP/MAZEEP operations, these 56 reconstructed accidents were simulated for the speed reductions of 3, 5, and 7 MPH. These accidents consisted of 14 accidents involving fatalities and 42 non-fatal injury accidents. They included both intrusions as well as non-intrusion accidents. The results in terms of number of fatal, serious injury, and moderate injury accidents prevented, had a severity reduction, or had no change are summarized in Table 8.

3 mph Reduction			
Injury Severity	Moderate	Serious	Fatal
Prevented	7%	8%	7%
Severity Reduction	27%	27%	7%
No Change	67%	65%	87%
5 mph Reduction			
Injury Severity	Moderate	Serious	Fatal
Prevented	33%	19%	27%
Severity Reduction	20%	35%	7%
No Change	47%	46%	67%
7 mph Reduction			
Injury Severity	Moderate	Serious	Fatal
Prevented	47%	31%	27%
Severity Reduction	27%	27%	7%
No Change	27%	42%	67%

Table 8. The Outcome of 56 Injury Accident Simulations with 3 mph, 5 mph, and 7 mph Initial Speed Reductions Represented by Injury Severity Levels.

The data in this table clearly shows the safety benefit of the incremental speed reduction due to use of COZEEP/MAZEEP operations.

The following conclusions are derived from the data in Table 8:

- For a 3 MPH incremental reduction in speed, 7% of fatal accidents would be prevented and in 7% of non-fatal injury accidents there would be a reduction of injury severity.
- For a 5 MPH as well as a 7 MPH incremental reduction in speed, 27% of fatal accidents would be prevented and in 7% of non-fatal injury accidents there would be a reduction of injury severity.

If we assume that this data applies to all work zone accidents summarized in Table 5, then the standard cost values indicated in Table 1 can be used to evaluate the incremental cost benefits associated with each of these speed reductions as a result of COZEEP/MAZEEP operations.

The following conclusions can be reached:

- Considering only the outcome of fatal accidents (in order to simplify the analysis) as a result of incremental speed reductions, then the cost benefit of COZEEP/MAZEEP are as follows:
    - For an incremental speed reduction of only 3 MPH, there will be a reduction in cost of fatalities of approximately $9.3 Million per year.
    - For an incremental speed reduction of 5 MPH and 7 MPH, the reduction in cost of fatalities will increase to approximately $22.9 Million per year.
    - If we consider the reduction of severity of other injuries then the benefits would even have higher values.

In order to evaluate the extent to which the number of accidents involving errant vehicles entering a work zone will be affected by COZEEP/MAZEEP operations, the 696 CHP accident reports were re-evaluated. A total of 347 of these involved intrusion into the work zone. Re-evaluating the CHP accident reports for these in more detailed indicated that only 90 of these accident reports had sufficient data on collision parameters that could be reconstructed using PC-Crash. It should be noted that injuries were not considered in this evaluation only accident causation was analyzed using simulation of these reconstructed accidents. The simulations were used to determine how many of such accidents could be prevented if there was incremental speed reductions of 3, 5, and 7 MPH as expected from COZEEP/MAZEEP operations. The results are tabulated in Table 9. It should be pointed out that the 90 intrusion accidents reconstructed all had some level of property damage.

3 mph Reduction		
	Number of Simulations	Percent Outcome
Prevented	3	3%
Intrusion	16	18%
Intrusion with PDO	71	79%
5 mph Reduction		
	Number of Simulations	Percent Outcome
Prevented	10	11%
Intrusion	26	29%
Intrusion with PDO	54	60%
7 mph Reduction		
	Number of Simulations	Percent Outcome
Prevented	18	20%
Intrusion	23	26%
Intrusion with PDO	49	54%

Table 9. Percentage Reduction in the Number of Intrusion Accidents as a Result of Incremental Speed Reductions.

In the data in Table 9, the "Prevented" accidents refers to the accidents that would result in no intrusions as a result of the specified speed reductions. Those indicated as "Intrusion" refers to those accidents would still involve intrusion into the work zone but resulted in no property damage.

The following conclusions are derived from the data in Table 9:

- For a 3 MPH incremental reductions in speed, 3% of intrusions into highway work zones were prevented and 18% of the intrusion accidents although not prevented, did not resolve in any property damage.

- For a 5 MPH incremental reductions in speed, 11% of intrusions into highway work zones were prevented and 29% of the intrusion accidents, although not prevented, did not resolve in any property damage.

- For a 7 MPH incremental reductions in speed, 20% of intrusions into highway work zones were prevented and 26% of the intrusion accidents, although not prevented, did not resolve in any property damage.

- The overall data show a steady increase in prevention of accidents involving intrusions into the highway work zone with increased incremental reduction in the average traffic speeds.

Limitations

1. The results obtained are based on relatively limited data and are not based on statistical analysis. They should, therefore, be used cautiously.

2. The traffic and other conditions at the test sites varied depending on the actual construction and maintenance work being performed as well as the traffic conditions at the time of the test and were not completely uniform.

3. Data collection in the rural areas was much more limited due to lower number of tests that could be scheduled during this study as compared to those performed in the urban areas.

4. The cost benefit analysis results only provide sample type calculations and should be used carefully accounting for the assumptions made and the limited number of accidents reconstructed.

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APPENDIX A: THE SURVEY

This appendix includes the survey in the form that was provided to the practitioners.

WZ safety practitioner survey

We need your opinion on how to improve work zone safety. Specifically, what are your thoughts on having CHP vehicles visibly present at a work zone? For example, do you think having COZEEP (CHP at a construction site) or MAZEEP (CHP at a maintenance work site) improves safety in general? If so, how and under what conditions?

All of you who see first hand how traffic responds when CHP is present have the most valuable knowledge. This survey wants to capture this knowledge and your experiences. We look forward to reading and gathering everyone's opinions.

Your participation, whether it is complete or partial, is completely voluntary and anonymous. We will not be recording your identity or any identifying information. We only wish to collect your opinions in an effort to improve the safety of highway work zones.

Many thanks for your time and cooperation!

Map of Caltrans districts

WZ_safety_practitioner_survey

1. Please use the following drop-down boxes to describe in which Caltrans district(s) you work and how frequently. Base your answer(s) on the last 12 months. The above map shows which counties are in each Caltrans district. Total percentage should add up to 100%.

	Caltrans District #:	% of time worked:
Primary District and % of time		
2nd District/ time% (optional):		
3rd District/ time% (optional):		
4th District/ time% (optional):		
5th District/ time% (optional):		

Please provide additional information here:

2. Please indicate what percentage of your time has been working on each road type. Use the last twelve months as the basis for your answers.

	0	0 - 24%	25% - 49%	50% - 74%	75% - 99%	100%
Undivided highway						
Divided highway: 1 or 2 lanes in each direction						
Divided highway: 3 or 4 lanes in each direction						
Divided highway: 5 or more lanes in each direction						

Please provide additional information here:

3. Does the presence of CHP at a work zone keep drivers from exceeding the posted speed limit? Rate your experiences between 1 (no effect on driver's speeds) to 5 (huge effect where everyone stays within the posted speed limit).

	1 (no effect)	2	3	4	5 (huge effect)	No experience
COZEEP						
MAZEEP						

Please provide additional information here:

4. Does the use of COZEEP/MAZEEP increase traffic congestion and subsequent queuing on the highway near the work zone? Rate from 1 (no effect on congestion) to 5 (almost always creates congestion).

	1 (no effect)	2	3	4	5 (almost always)	No experience
COZEEP						
MAZEEP						

Please provide additional information here:

5. Does the use of COZEEP/MAZEEP improve the safety of workers in highway work zones? Rate from 1 (No, not at all) to 5 (Yes, almost always).

	1 (Not at all)	2	3	4	5 (almost always)	No experience
COZEEP						
MAZEEP						

Please provide additional information here:

6. Does the use of COZEEP/MAZEEP improve the safety of the traveling public in highway work zones? Rate from 1 (No, not at all) to 5 (Yes, almost always).

	1 (not at all)	2	3	4	5 (almost always)	No experience
COZEEP						
MAZEEP						

Please provide additional information here:

7. Do you think drivers are more attentive when CHP vehicles are seen at a work zone? Rate from 1 (No, not at all) to 5 (Yes, almost always).

	1 (not at all)	2	3	4	5 (almost always)	No experience
COZEEP						
MAZEEP						

Please provide additional information here:)

8. When COZEEP/MAZEEP operations are used, what is the best number of CHP vehicles to be used?

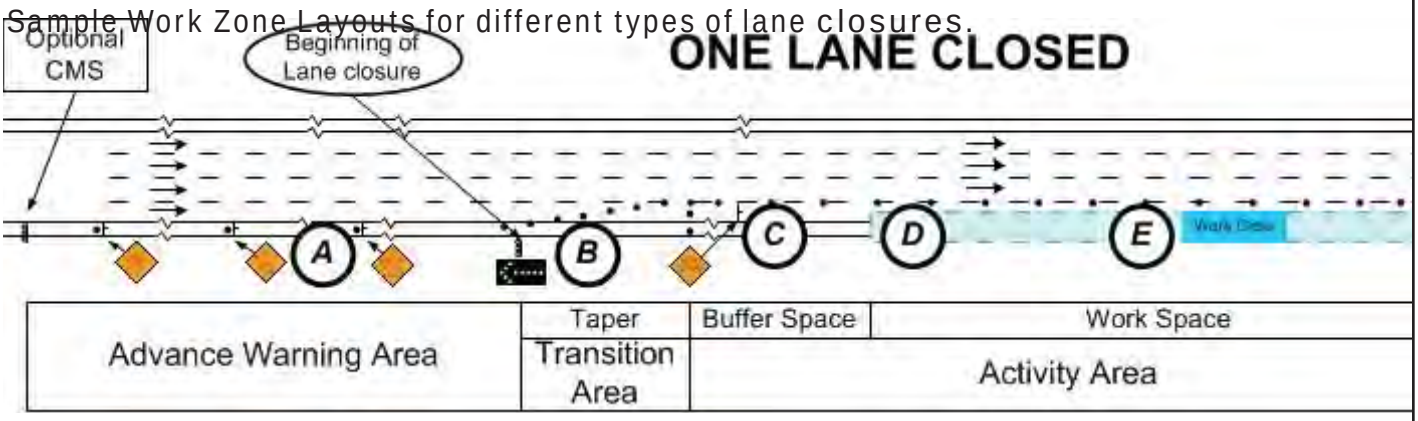
	1	2	More than 2	I have no opinion
COZEEP				
MAZEEP				

Please provide additional information here:

The following figure shows a sample highway work zone with 1 lane closed. The following two questions relate to this figure and reference various work zone regions denoted by letters "A" through "F". The letter denotations are as follows: :

(A) Upstream of Taper
(B) Transition Area
(C) Buffer Space
(D) End of Buffer Space
(E) Adjacent to work crew
(F) Termination

Sample Work Zone Layouts for different types of lane closures.



9. Please refer to the figure above where one lane of traffic is closed. In your experience, where are CHP vehicles typically placed when COZEEP/MAZEEP is used? Please choose among A, B, C, D, E and/or F. Please provide any details you see fit.

	(A) Upstream of Taper	(B) Transition Area	(C) Buffer Space	(D) End of Buffer Space	(E) Adjacent to work crew	(F) Termination
COZEEP						
MAZEEP						

Please provide additional information here:

10. Refer to the above figure where one lane of traffic is closed. Based on your experience and judgement, where would you recommend CHP vehicles be placed to maximize safety for all? Please choose A, B, C, D, E and/or F. Please provide any details you see fit.

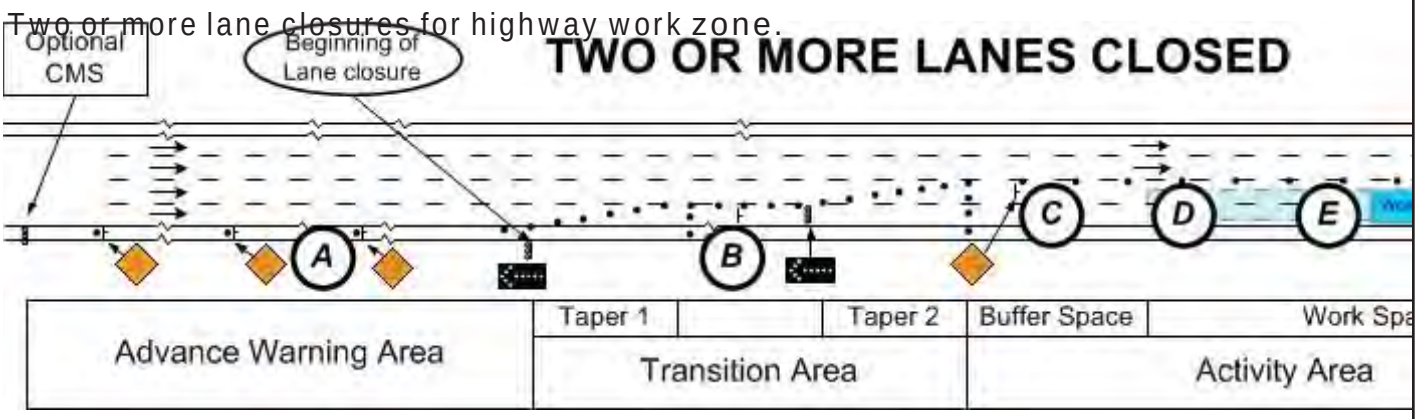
	(A) Upstream of Taper	(B) Transition Area	(C) Buffer Space	(D) End of Buffer Space	(E) Adjacent to work crew	(F) Termination
COZEEP						
MAZEEP						

Additional Information:

The following figure shows a sample highway work zone with 2 (or more) lanes closed. The following two questions relate to this figure and reference various work zone regions denoted by letters "A" through "F". The letter denotations are as follows: :

(A) Upstream of Taper
(B) Transition Area
(C) Buffer Space
(D) End of Buffer Space
(E) Adjacent to work crew
(F) Termination

Two or more lane closures for highway work zone.



11. Please refer to the figure above where two lanes of traffic are closed. Based on your experience and judgement, where are CHP vehicles typically placed when COZEEP/MAZEEP is used? Please choose among A, B, C, D, E and/or F. Please provide any details you see fit.

	(A) Upstream of Taper	(B) Transition Area	(C) Buffer Space	(D) End of Buffer Space	(E) Adjacent to work crew	(F) Termination
COZEEP						
MAZEEP						

Please provide additional information here:

12. Refer to the above figure where twoormore lanes of traffic are closed. Based on your experience and judgement, where would you recommend CHP vehicles be placed to provide most benefit to workers on the road. Please choose among A, B, C, D, E and/or F. Please provide any details you see fit.

	(A) Upstream of Taper	(B) Transition Area	(C) Buffer Space	(D) End of Buffer Space	(E) Adjacent to work crew	(F) Termination
COZEEP						
MAZEEP						

Please provide additional information here:

13. Under what conditions do you feel COZEEP/MAZEEP should be considered higher priority?

	COZEEP	MAZEEP
During daytime operations		
During nighttime operations		
On level/straight highways		
On graded/curved highways		
During high volume traffic times		
During low volume traffic times		

Please provide additional information here:

14. Thank you for your time and effort. If you wish to provide comments about anything with respect to this survey or about work zone safety in general, please feel free to tell us what you think!

5

6

15. Would you like a researcher to contact you directly so you can provide more information/feedback ? If yes, please provide your email address and/or phone number in the following area:

5

THANK YOU! We appreciate your time. Please enjoy the rest of your day!

APPENDIX B: Test Data

This appendix includes the data from all the tests performed as part of this study. The detailed data on average traffic speeds at different iCone (measurement) locations for each test is plotted above a Google Earth ™ image of the site. Each plot includes a baseline plot of a test that did not involve any CHP presence. Other information including the date, the weather condition and the location of each test as well as the nature of the lane closure together with plots of average traffic speeds at different iCone locations are also provide in each plate containing the plots of the test data.

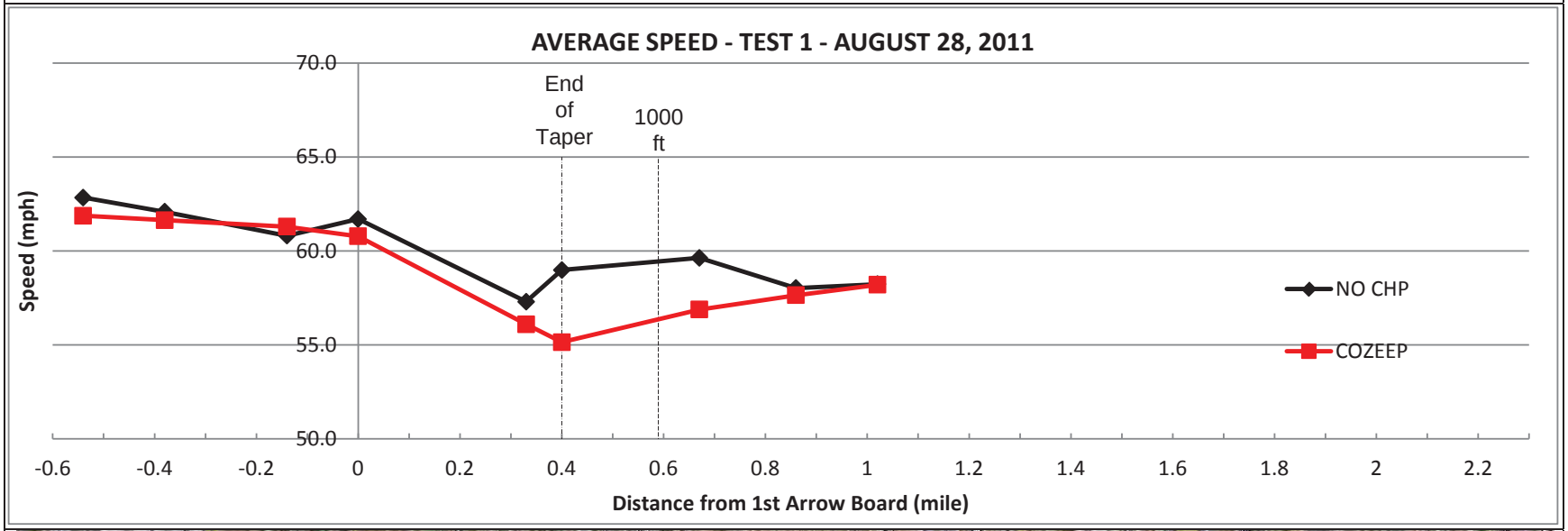
COZEEP/MAZEEP Test Data

TEST 1 AUG. 28, 2011 - SR 163 Northbound - Friars Ave to Genesee Ave

Description:	**Conditions:**	**CHP Contact:**
Sunday Night. Fair Weather, 2 right lanes closed. Work along shoulder installing dike. Machine moved from Genessee south toward iCone 808 *SD-163 - Grinding and Shoulder Rehab Project (NB and SB) Project No. 11-239304*	00:35 – 01:30 NO CHP 01:30 – 02:30 COZEEP	1 verbal only (2 logs) Slow traffic

Same location as Test 2. Medium length closure. 3 Lanes open. Approach speeds (-.5mi to 0.0 at the arrowboard) ~62mph. Traffic speed lower because of hill climb 300ft. Drop in the speed plot at iCone 808 may be due to slower on-ramp traffic from Friar Ave. Second lane taken is a new lane. Work moved from north to south during the night. Work zone speed reduced by about 3 mph to 56 mph. Slow traffic.

LEGEND: - iCone - First Arrow board - Lane Closed - CHP



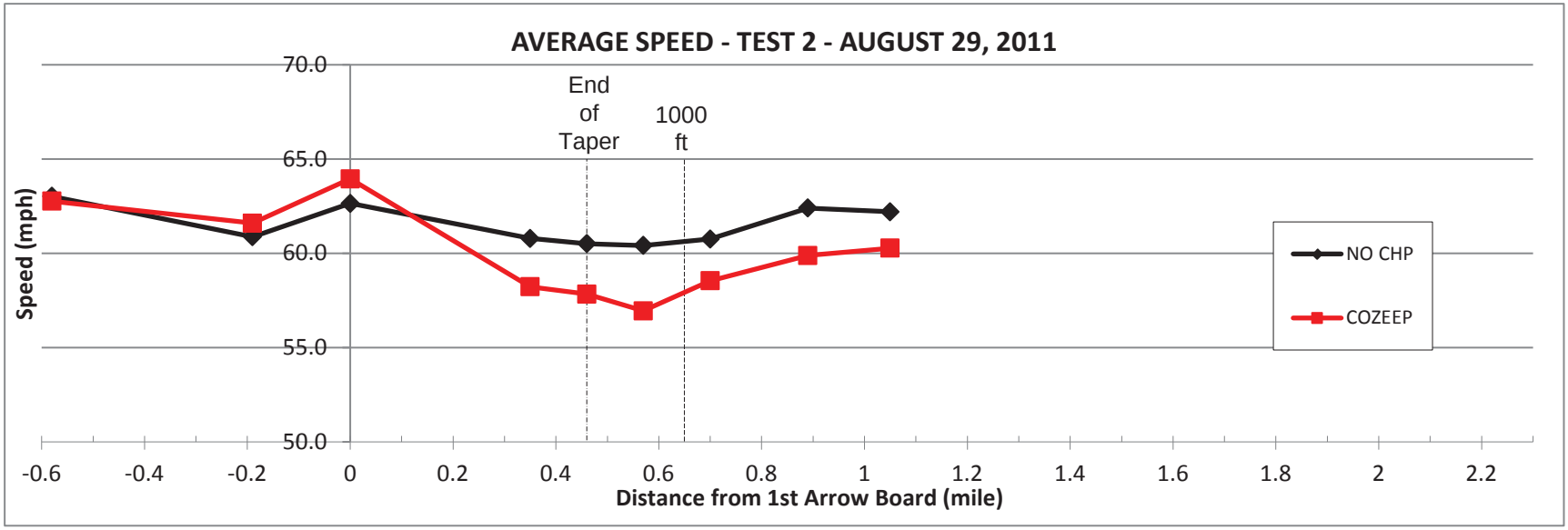
TEST 2 AUG. 29, 2011 - SR 163 Northbound - Friars Ave to Genesee Ave

Description:	**Conditions:**	**CHP Contact:**
Monday Night. 2 right lanes closed. Work along shoulder back filling dike. Work moved from Friar to Genesee. Trucks unloading fill into machine with hopper. *SD-163 - Grinding and Shoulder Rehab Project (NB and SB) Project No. 11-239304*	23:15 – 01:00 NO CHP 01:00 – 02:05 COZEEP	1 DUI. only (0 Logs) Slow traffic.

Same location as Test 1. Medium length closure. Approach speeds below 64mph. Traffic speed is lower because of hill climb 300ft. A decrease is observed in the speed plot at iCone 433 due to on-ramp traffic from Friar is not as obvious. Second lane taken is a new lane. Work moved from south to north during the night. Speeds generally higher than previous night

Work zone speed reduced by about 4 mph to 57 mph. COZEEP speed reduction effective over longer distance as expected. Slow traffic.

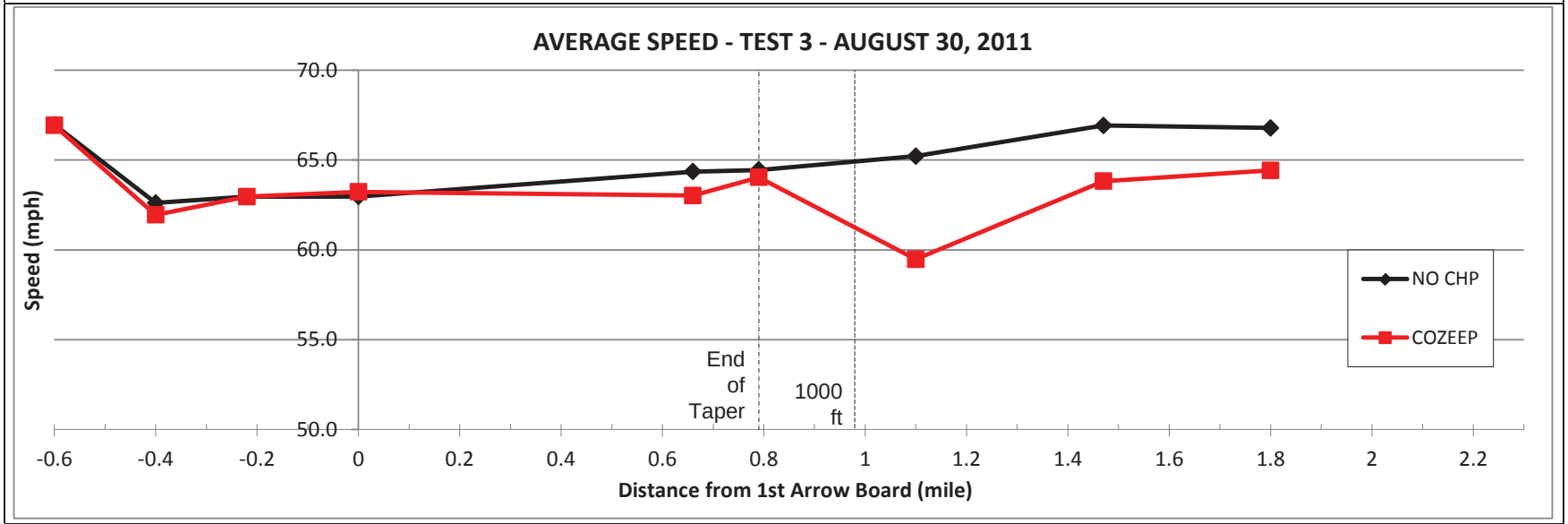
LEGEND: - iCone - First Arrow board - Lane Closed



TEST 3 AUG. 30, 2011 - I 805 Northbound - South of Mira Mesa Ave to I5

Description:	**Conditions:**	**CHP Contact:**
Tuesday Night. 2 left lanes closed. Excavator in median loading dump truck loading at Lane #1. Trucks entering and exiting. *SD-805/Carroll Canyon Road Project No.: 11-2T0404*	23:15 – 00:45 NO CHP 00:45 – 01:45 COZEEP	2 verbal, 2 citations =4.stops (3 Logs)

Similar to Tests 4 and 6. Long closure. Approach speeds drops to 63 mph but then increases due to wide open downhill road. Elevation drops 300' from beginning of lane closure and then 2 more lanes are open.
COZEEP unit at iCone 812 clearly slows traffic. COZEEP reduces speed by 5 mph to 59 mph.
ICone 433 at -1.41 mi is plotted at -0.6 mi
LEGEND: - iCone - First Arrow board - Lane Closed - CHP - Work zone



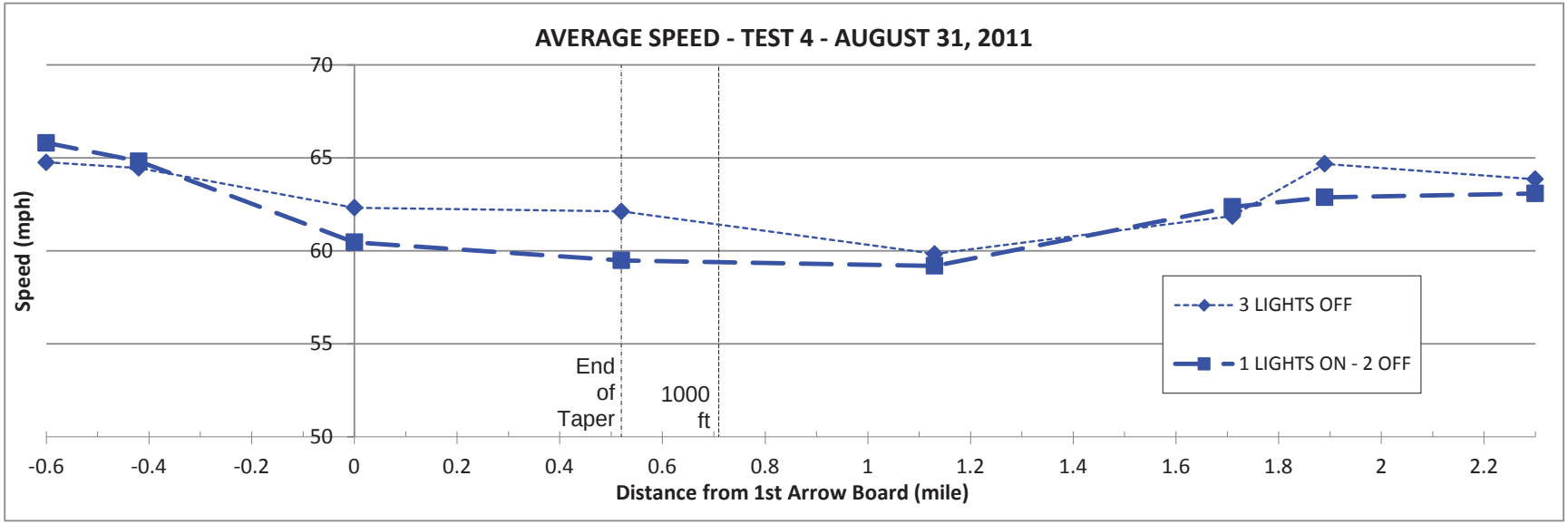
TEST 4 AUG. 31, 2011 - I 805 Northbound - La Jolla Village Dr to I5

Description:	**Conditions: ACOZEEP variations**	**CHP Contact:**
Wednesday Night. 2 left lanes closed. Excavator in median loading dump truck loading at Lane #1. Trucks entering and exiting. *SD-805/Carroll Canyon Road Project No.: 11-2T0404*	00:30 – 01:00 All 3 LIGHTS OFF 01:00 – 03:00 1 LIGHTS ON, 2 LIGHTS OFF	8 stops in closure (1 Log) Accident response w/ DUI on opposite side

Similar to Tests 3 and 6. Long closure. Approach speed 65+ mph. Long Closure. Accident activity on the opposite side of the freeway 23:00-0:00 . CHP were in full enforcement mode and often not in the closure. In the 1 CHP w/ Lights On condition, other officers were in place with lights off 'dark'. Speed profile is similar to previous night except that CHP is positioned further upstream. Closure begins earlier too. Data suggests that 'dark' CHP units are as prominent as CHP units with lights. This was suggested in discussions with officers. This test does not show a standard COZEEP configuration nor NO CHP condition. Mostly representative of variations to ACOZEEP and shows speeds reduced over 2 miles.

ICone 431 at -0.91 mi is plotted at -0.6 mi

LEGEND: - iCone - First Arrow board - Lane Closed - CHP - Work zone

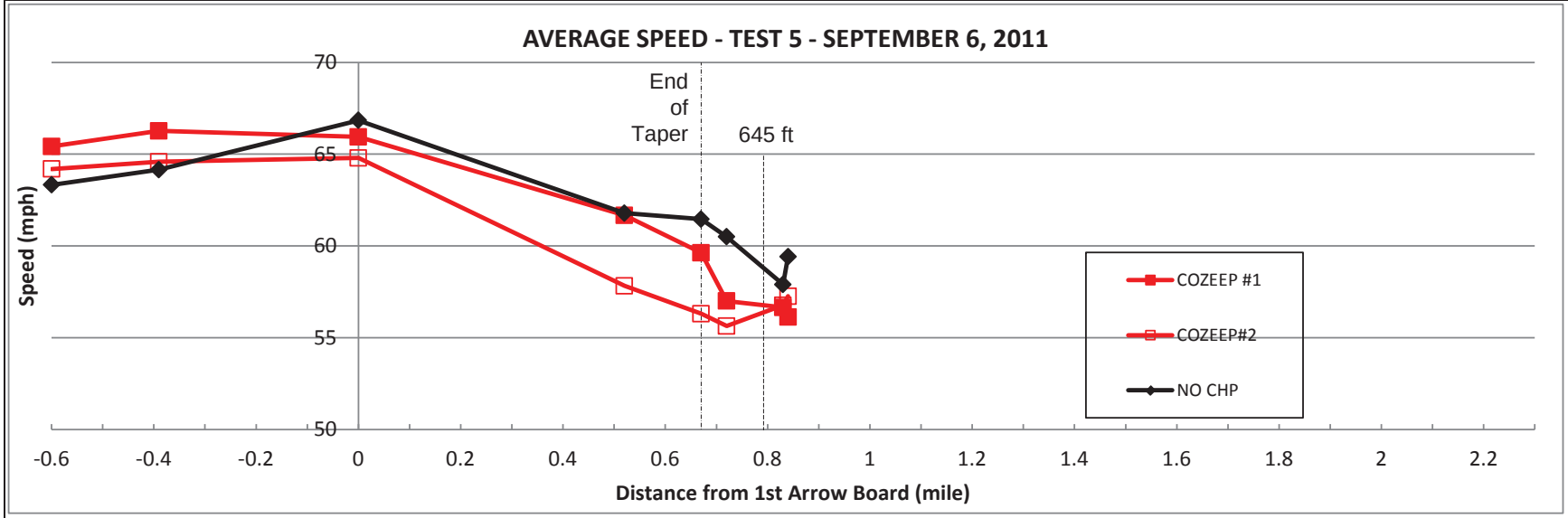


TEST 5 SEPT 6, 2011 - I 805 North - Nobel Dr Exit to La Jolla Village Dr

Description:	**Conditions:**	**CHP Contact:**
Tuesday Night after Labor Day. 2 right lanes closed first part of evening and then 2 left lanes. Work on the outside edges of overpass. *SD-805/La Jolla Village Drive Project* *Project No. 11-089754*	23:00-23:15 NO CHP 23:15 - 00:00 COZEEP #1 00:45 - 01:45 Lane closure moved to other side 01:45 - 02:45 COZEEP #2	Yes Qty not logged (1 Log for 3 units)

Approach speed is 67mph Short closure (0.84 mi) with a single point of work at the overpass. In all the tests the CHP units were located in close proximity to each other and the work zone. In this case the CHP and work zone are clearly visible before the 2nd Arrowboard at iCone 431. K-rail is up against the edges of the lanes slows drivers. In this case the lights at the work zone and multiple CHP lights were extremely prominent. The NO CHP test covers a shorter time period than ideal. Speeds are reduced to about 57 mph for COZEEP.

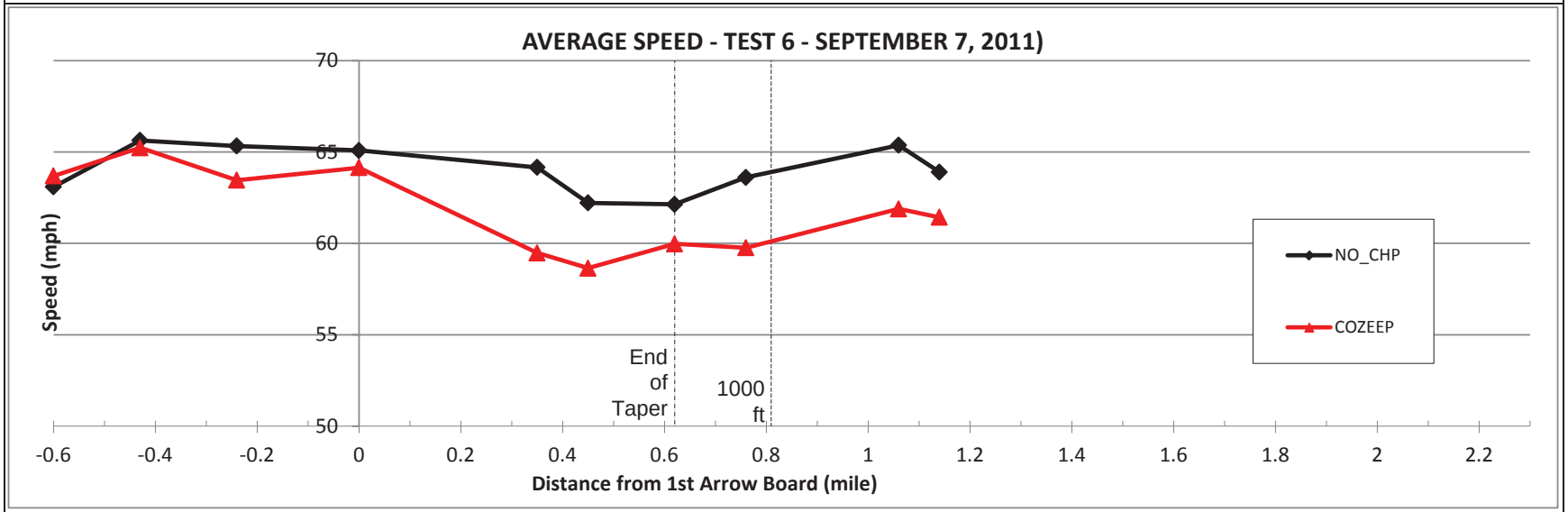
ICone 428 at -1.03 mi is plotted at -0.6 mi LEGEND: - iCone - First Arrow board - Lane Closed



TEST 6 SEPT 7, 2011 - I 805 Northbound - Nobel Dr Exit to La Jolla Village Dr

Description:	**Conditions:**	**CHP Contact:**
Wednesday Night. 2 left lanes closed. Excavator in median loading dump truck loading at Lane #1. Trucks entering and exiting. *SD-805/La Jolla Village Drive Project Project No. 11-089754*	23:30 - 00:00 NO CHP 00:00 - 01:30 COZEEP	2 verbal, 3 citations Total 5 stops in closure DUI + misc stop out of closure (2 logs)

Similar to Test 3 and 4. Medium length Approach speed 65+ mph. Length is shorter than Test 3 and 4. Speeds are lower. Maybe because the elevation drops only 170' from beginning of lane closure and only 2 lanes are open with narrow shoulders and merging. At iCone 811 the 2nd lane is being taken at a point where traffic is both merging on & off. This may cause the observed dip in speeds through midnight. It is observed that COZEEP unit at iCone 811 reduces speed ~5mph to 58mph. The dip to 56 mph may be due to congestion. Last iCone might capture slower on ramp traffic resulting in unexpected drop in speed.
ICone 431 at -3.03 mi is plotted at -0.6 mi
LEGEND: - iCone - First Arrow board - Lane Closed - CHP - Work zone



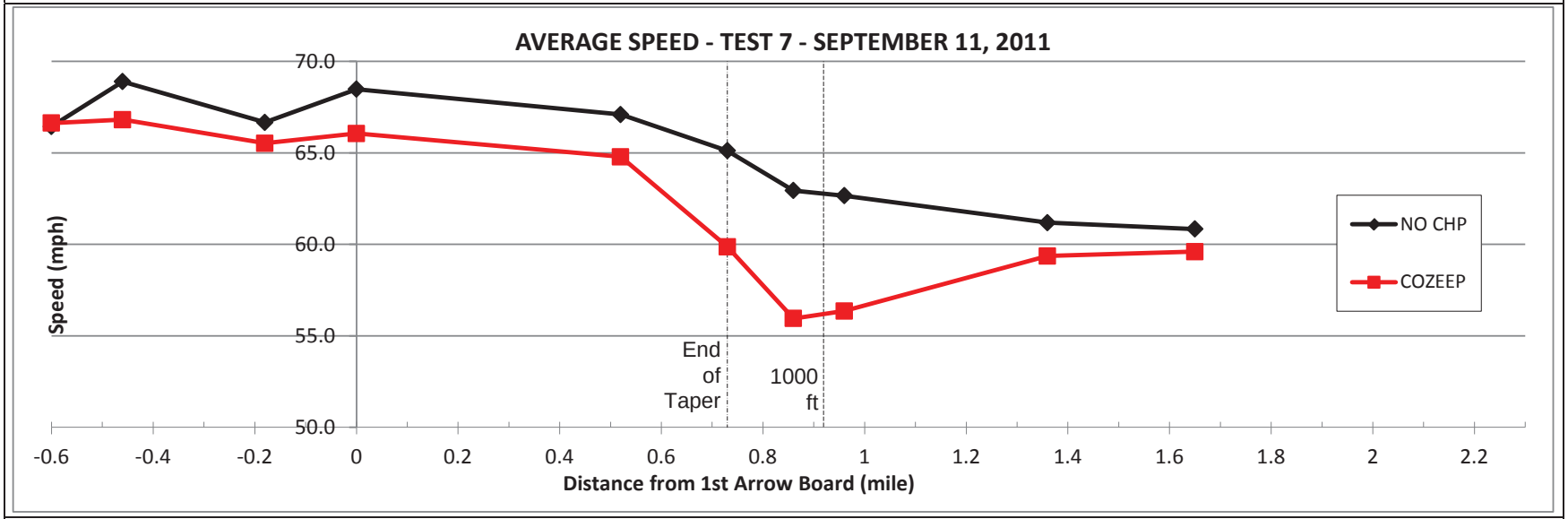
TEST 7 SEPT 11, 2011 – I 805 Southbound - Before SR52 to Balboa Ave

Description:	**Conditions:**	**CHP Contact:**
Sunday Night. 2 left lanes closed. Work on lanes 1 and 2 repairing concrete. *SD-805 Grinding and Shoulder Rehab Project Project No. 11-2M01704*	01:00 - 01:30 NO CHP 01:30 - 02:30 COZEEP	4 verb + 4 cit. + 1 other+ DUI = 10 in closure. 13 Stops total (3 Logs)

Similar to Test 8. Approach speed is 67+ mph. The closure was long and 2 crews began at iCone 810 and continued to move down the road during the course of the night. The CHP units were clearly visible from before the beginning of the lane closure at iCone 812. The extra CHP units reduced speeds along an additional mile. In this case the COZEEP reduced speeds by up to 8mph.

ICone 432 at -1.57 mi is plotted at -0.6 mi

LEGEND: - iCone - First Arrow board - Lane Closed - CHP

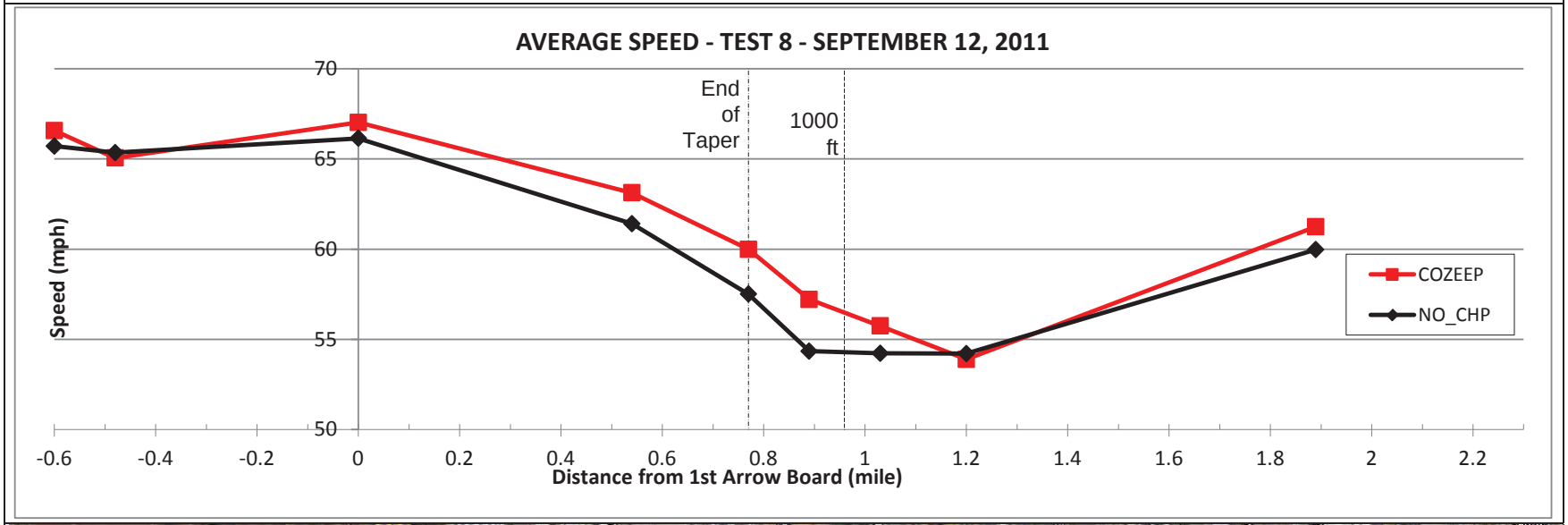


TEST 8 SEPT 12, 2011 - I 805 Southbound - SR52 to SR 163

Description:	**Conditions:**	**CHP Contact:**
Monday Night. 2 left lanes closed. Work on lanes 1 and 2 repairing concrete. Monitored up to Balboa. Limited work beyond that point. *SD-805 Grinding and Shoulder Rehab Project Project No. 11-2M01704*	21:45 - 22:30 NO CHP 23:30 - 00:30 COZEEP	Tested no contact during ACOZEEP (3 logs)

Similar to Test 7. Approach speed is 67 mph. The closure was long and 2 crews began at iCone 430 and continued to move down the road during the course of the night. The CHP unit was clearly visible from before the beginning of the lane closure at iCone 812. The NO CHP conditions till 23:15 captured reduced speeds due to congestion. ICone 433 speed could be considered a nominal speed through the work zone since it is located well past the very active work zone and CHP units.

ICone 431 at -1.84 mi is plotted at -0.6 mi LEGEND: - iCone - First Arrow board - Lane Closed - CHP



AUG 21, 2012 – I-5 Northbound – Redding, CA

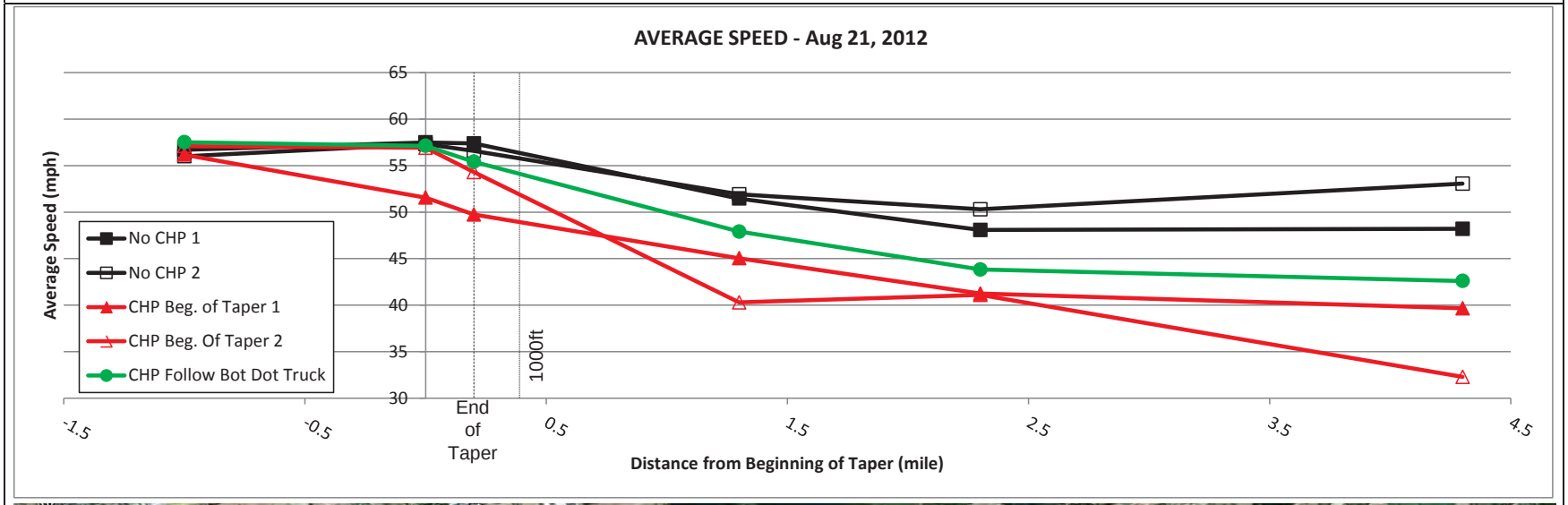
Description:
Tuesday 7 PM to 1 AM.
Three iCones were deployed at first sign of lane closur, beginning of taper, end of taper, with the remaining three distributed along the closure until the end. The work was fog sealing for the #2 lane. The process involves grinding off reflective marker, spray oil on the surface, spray sand, and sweeps off the sand.
CHP had many activities, including: provide rolling traffic for the oil spray truck, and shadowing various Caltrans vehicles such as bot dot trucks and sweepers, as well as cone trucks.

Conditions:

20:00 - 20:40	CHP beginning of taper 1
21:20 - 21:55	CHP beginning of taper 2
21:55 - 23:15	CHP following Bott Dot truck
23:15 - 23:45	No CHP 1
23:45 - 1:00	No CHP 2

CHP Contact:
No known contacts

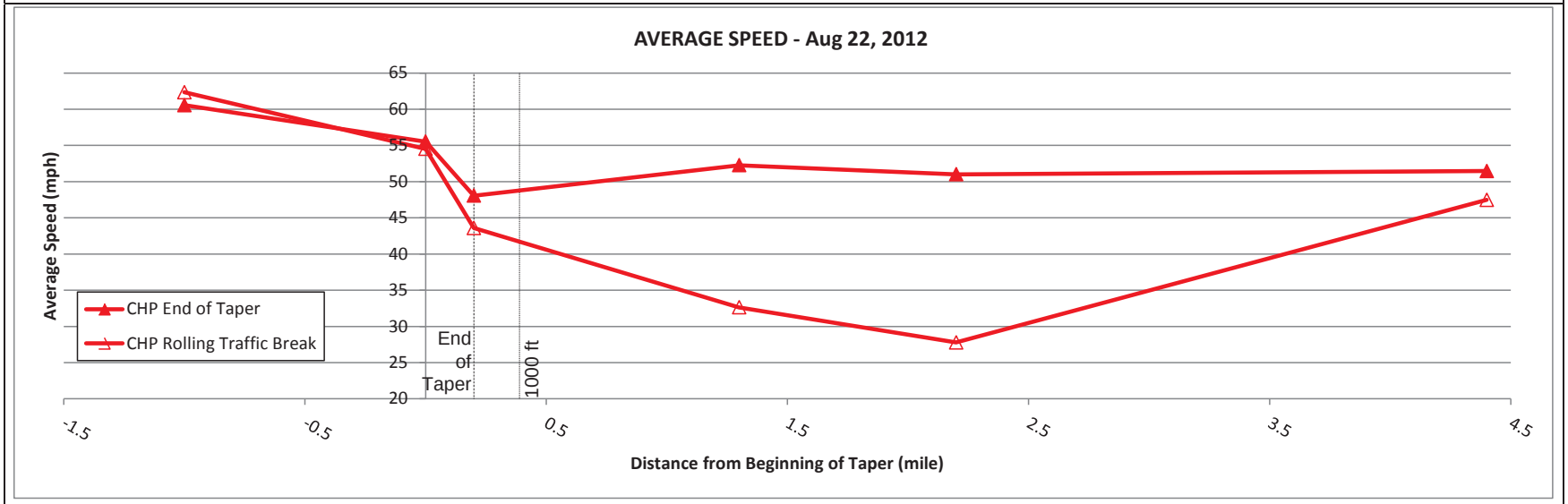
LEGEND: - iCone - Arrow board - Lane Closed - CHP



AUG 22, 2012 – I-5 Northbound – Redding, CA

Description:	**Conditions:**	**CHP Contact:**
Tuesday 7 PM to 1 AM. Three iCones were deployed at first sign of lane closur, beginning of taper, end of taper, with the remaining three distributed along the closure until the end. The work was fog sealing for the #1 lane. The process involves grinding off reflective marker, spray oil on the surface, spray sand, and sweeps off the sand. CHP had many activities, including: provide rolling traffic for the oil spray truck, and shadowing various Caltrans vehicles such as bot dot trucks and sweepers, as well as cone trucks. This test did not have any clearly defined NO CHP condition.	20:00 - 20:25 CHP Stationary End of Taper 20:25 - 20:45 CHP Providing Rolling Traffic Break	No known contacts

LEGEND: - iCone - Arrow board - Lane Closed - CHP



SEP 11, 2012 – I-5 Southbound – Weed, CA

Description:
Tues 9 AM to 4 PM.
Closure is 4 miles long, on I-5 SB. The crew started on the south end of the closure, worked for two miles towards the north and picked up the closure for the two miles done. The iCones were initially set up with iCone 1004 at the end of closure, designated 1004A. This iCone was later moved to location 1004B after the closure reconfiguration.

CHP upstream position was not visible from the location of iCone 1000.

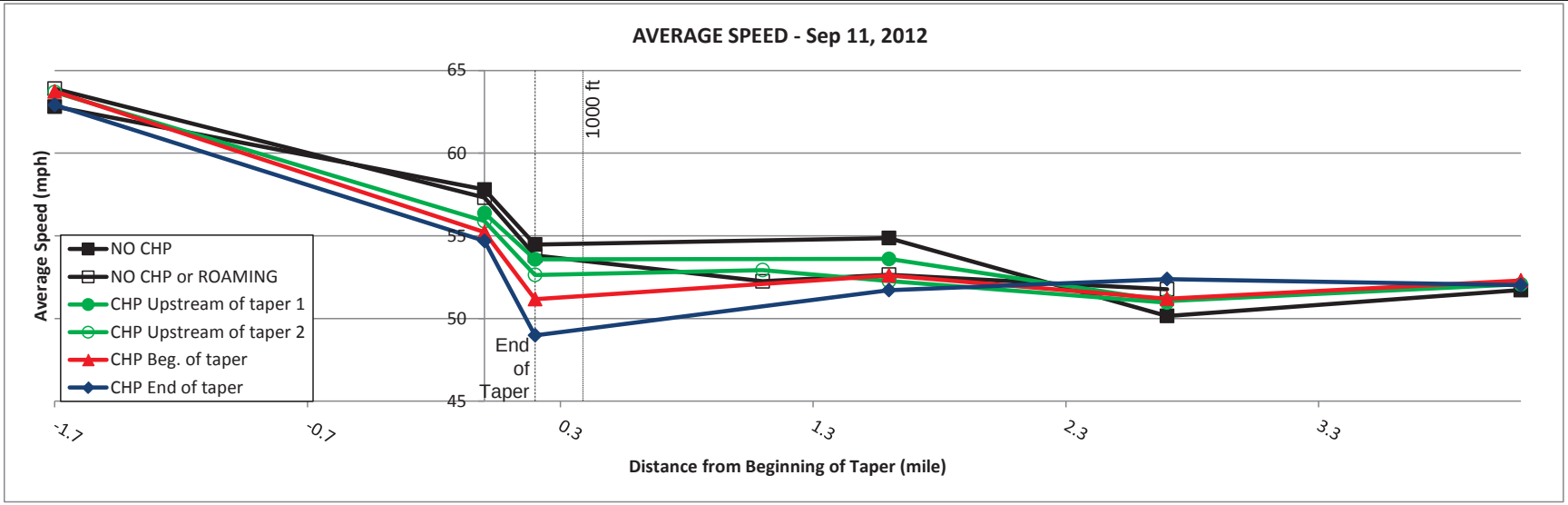
CMS Message: 55 ZONE AHEAD, LEFT LANE CLOSED

Conditions:

09:30 - 11:00	NO CHP
11:00 - 12:00	CHP upstream of taper 1
12:00 - 13:00	CHP beg. of taper
13:00 - 14:00	CHP end of taper
14:30 - 15:00	CHP upstream of taper 2
15:00 - 16:18	NO CHP or Roaming

CHP Contact:
CHP made 5 stops:
2 stops before 11:00 (NB), 14:05, 15:10, 15:40.
Each stop took about 20 min for CHP to return to original position. The 5th stop took 40min

LEGEND: - iCone - Arrow board - Lane Closed - CHP - CMS



SEP 12, 2012 – I-5 Southbound – Weed, CA

Description:
Wed 9 AM to 4 PM.
iCones located at first sign of lane closure (with reduced to 55mph warning), beginning of taper, end of taper, and the rest downstream at 1000 ft apart. This test closely resembles the configuration of a MAZEEP operation (short work area), even though the actual work is a construction operation.

CHP upstream position was visible from iCone 1000.

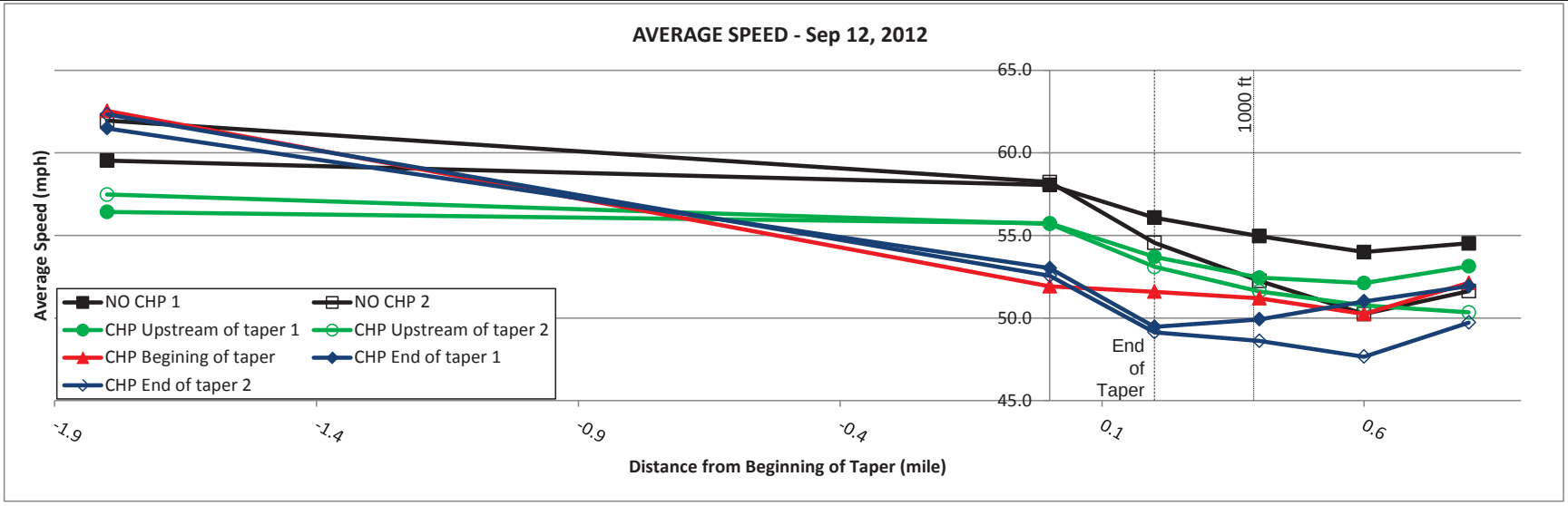
CMS Messages: LEFT LN CLOSED AHEAD, 55 MPH ZONE AHEAD

Conditions:

09:37 - 10:00	NO CHP 1
10:00 - 10:30	CHP Upstream of taper 1
11:00 - 12:00	CHP Begining of taper
12:00 - 13:00	CHP End of taper 1
13:00 - 14:00	NO CHP 2
14:00 - 15:00	CHP Upstream of taper 2
15:00 - 15:55	CHP End of taper 2

CHP Contact:
CHP made one stop between 10:30 and 10:52 on the opposite direction.

LEGEND: - iCone - Arrow board - Lane Closed - CHP - CMS

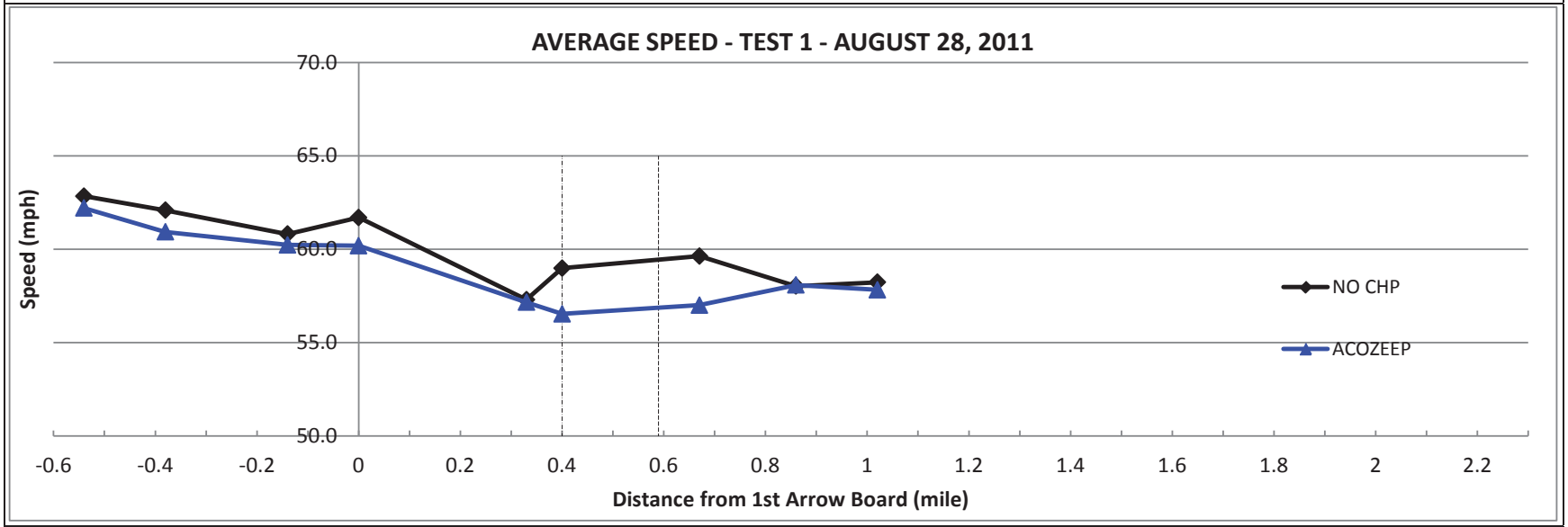


ACOZEEP Test Data

TEST 1 AUG. 28, 2011 - SR 163 Northbound - Friar Ave to Genesee Ave

Description:	**Conditions:**	**CHP Contact:**
Sunday Night. 2 right lanes closed. Work along shoulder installing dike. Machine moved from Genessee south toward iCone 808 *SD-163 - Grinding and Shoulder Rehab Project (NB and SB) Project No. 11-239304*	00:35 – 01:30 NO CHP 02: 30 – 03:00 ECOZEEP	1 verbal only (2 logs) Slow traffic

NOTES: Same location as Test 2. Medium length closure. 3 Lanes open. Approach speeds (-.5mi to 0.0 at the arrowboard) ~62mph. Traffic speed lower because of hill climb 300ft. Drop in the speed plot at iCone 808 may be due to slower on-ramp traffic from Friar Ave. Second lane taken is a new lane. Work moved from north to south during the night. Units sometimes hidden instead of off site. Possible reanalysis to eliminate low speed vehicles.
Work zone speed reductions for both conditions ~3mph to 56 mph. Slow traffic.
LEGEND: - iCone - First Arrow board - Lane Closed - CHP



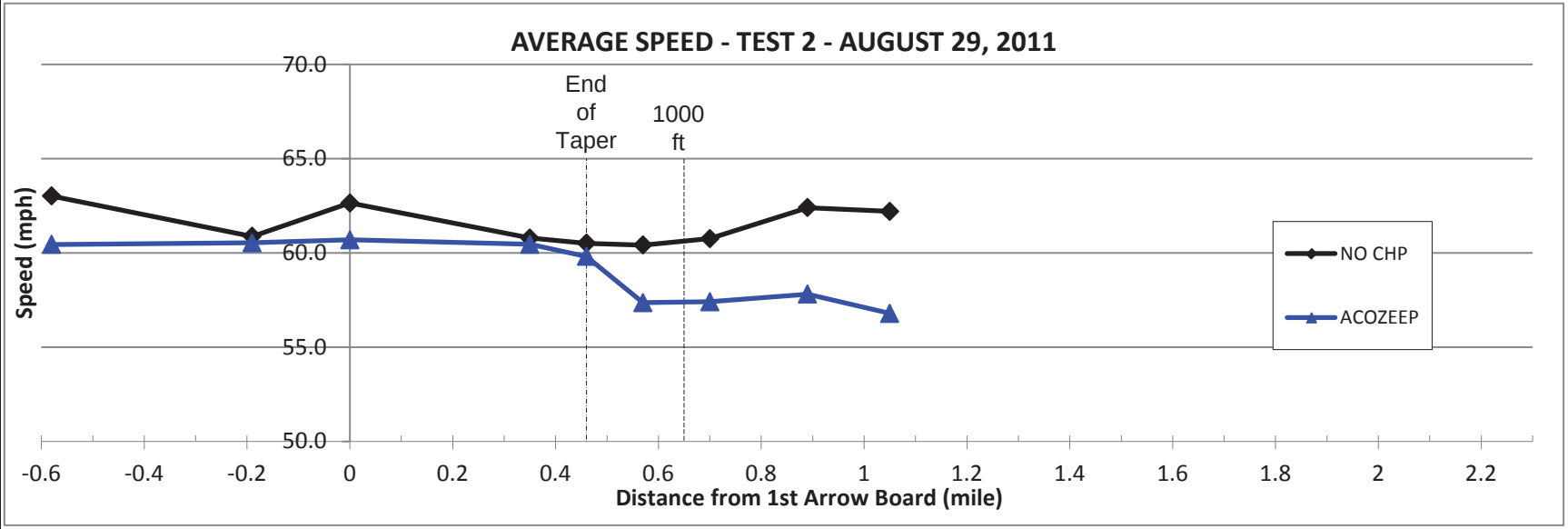
TEST 2 AUG. 29, 2011 - SR 163 Northbound - Friar Ave to Genesee Ave

Description:	**Conditions:**	**CHP Contact:**
Monday Night. 2 right lanes closed. Work along shoulder back filling dike. Work moved from Friar to Genesee. Trucks unloading fill into machine with hopper. *SD-163 - Grinding and Shoulder Rehab Project (NB and SB) Project No. 11-239304*	23:15 – 01:00 NO CHP 02:05 – 03:30 ECOZEEP	1 DUI. only (0 Logs) Slow traffic.

Same location as Test 1. Medium length closure. Approach speeds below 64mph. Traffic speed is lower because of hill climb 300ft. Drop in the speed plot at iCone 433 due to on-ramp traffic from Friar is not as obvious. Second lane taken is a new lane. Work moved from south to north during the night. Possible renalysis to eliminate low speed vehicles. Speeds generally higher than previous night

Work zone speed reductions for both conditions ~4mph to 57 mph. ECOZEEP speed reduction effective over longer distance as expected. Slow traffic.

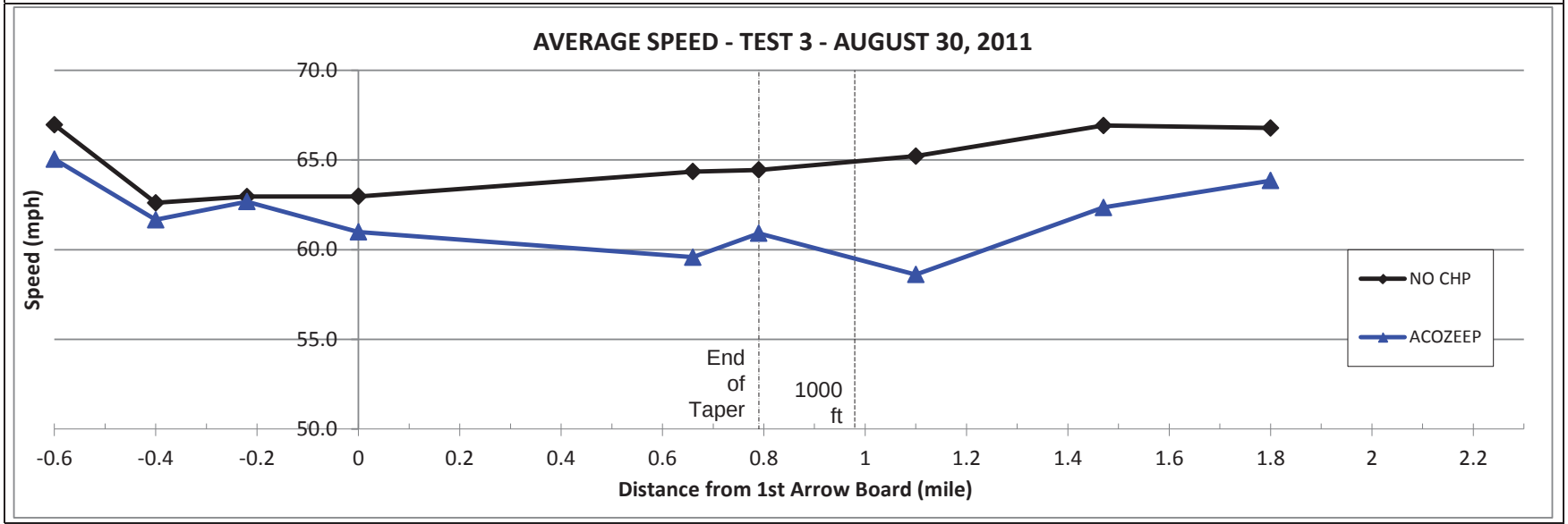
LEGEND: - iCone - First Arrow board - Lane Closed



TEST 3 AUG. 30, 2011 - I 805 Northbound - South of Mira Mesa Ave to I5

Description:	**Conditions:**	**CHP Contact:**
Tuesday Night. 2 left lanes closed. Excavator in median loading dump truck loading at Lane #1. Trucks entering and exiting. *SD-805/Carroll Canyon Road Project No.: 11-2T0404*	23:15 – 00:45 NO CHP 01:45 – 03:15 ECOZEEP	2 verbal, 2 citations =4.stops (3 Logs)

Similar to Tests 4 and 6. Long closure. Approach speeds drops to 63 mph but then increases due to wide open downhill road. Elevation drops 300' from beginning of lane closure and then 2 more lanes are open. COZEEP unit at iCone 812 clearly slows traffic. Under ECOZEEP units are distributed between the first arrowboard and the work zone at iCone 812. This is clearly visible in the plot. If one assumes that the downhill condition increases speed, the extra CHP officers are clearly slowing traffic down. ECOZEEP reducews speed by ~6 mph and traffic is slowed over longer distance. A good example of expected effects.
ICone 433 at -1.41 mi is plotted at -0.6 mi
LEGEND: - iCone - First Arrow board - Lane Closed - CHP - Work zone



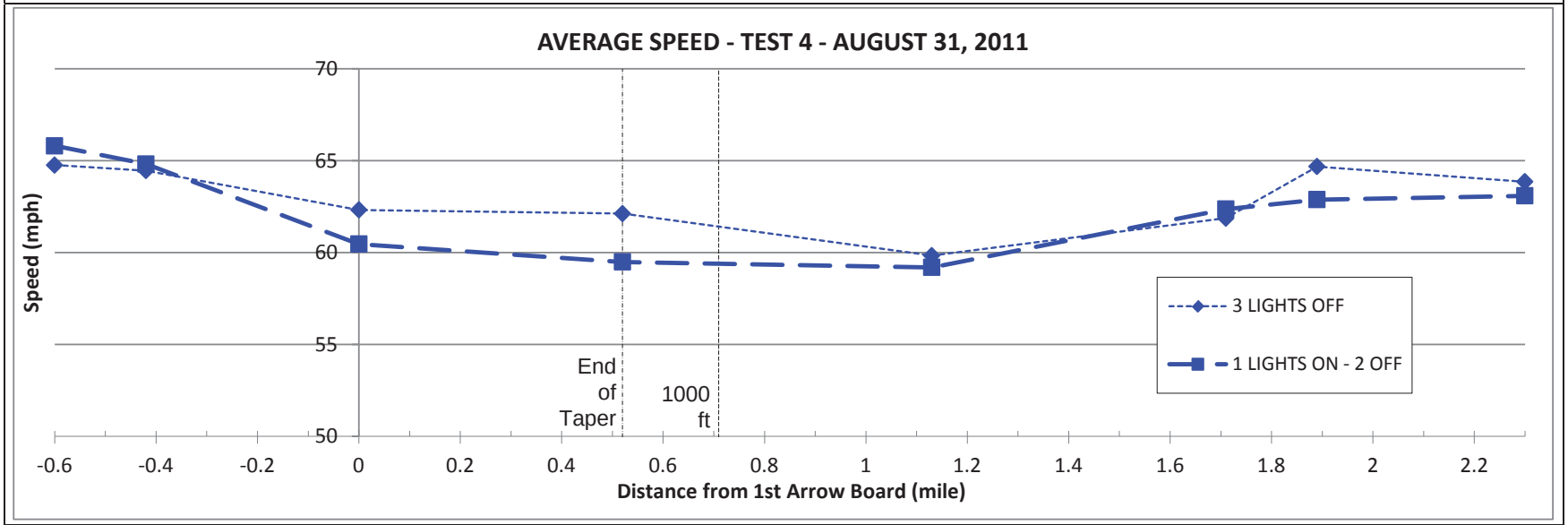
TEST 4 AUG. 31, 2011 - I 805 Northbound - La Jolla Village Dr to I5

Description:	**Conditions: ECOZEEP variations**	**CHP Contact:**
Wednesday Night. 2 left lanes closed. Excavator in median loading dump truck loading at Lane #1. Trucks entering and exiting. *SD-805/Carroll Canyon Road Project No.: 11-2T0404*	23:55 – 00:30 All 3 LIGHTS ON 00:30 – 01:00 All 3 LIGHTS OFF 01:00 – 03:00 1 LIGHTS ON, 2 LIGHTS OFF	8 stops in closure (1 Log) Accident response w/ DUI on opposite side

Similar to Tests 3 and 6. Long closure. Approach speed 65+ mph. Long Closure. Accident activity on the opposite side of the freeway 23:00-0:00 . CHP were in full enforcement mode and often not in the closure. In the 1 CHP w/ Lights On condition, other officers were in place with lights off 'dark'. First CHP clearly visible before the Lane Closed sign. Speed profile is similar to previous night except that CHP is positioned further upstream. Closure begins earlier too. Data suggests that 'dark' CHP units are as prominent as CHP units with lights. This was suggested in discussions with officers. This test does not show a standard COZEEP configuration nor NO CHP condition. Mostly representative of variations to ECOZEEP and shows speeds reduced over 2 miles.

ICone 431 at -0.91 mi is plotted at -0.6 mi

LEGEND: - iCone - First Arrow board - Lane Closed - CHP - Work zone



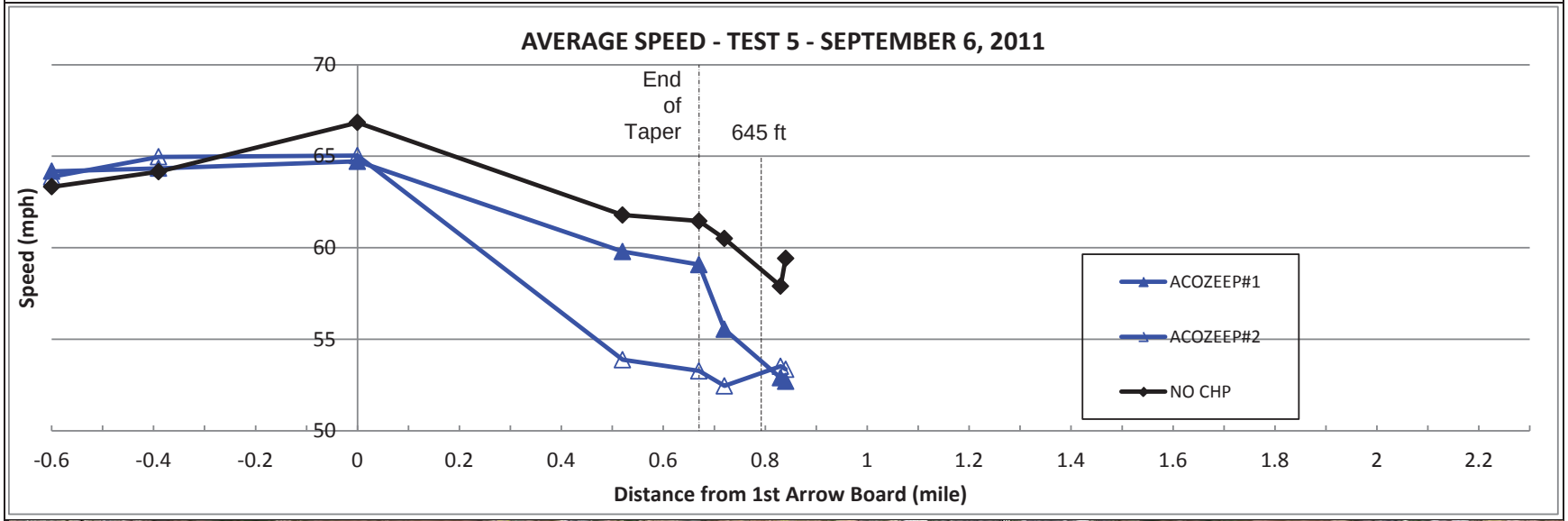
TEST 5 SEPT 6, 2011 - I 805 North - Nobel Dr Exit to La Jolla Village Dr

Description:	**Conditions:**	**CHP Contact:**
Tuesday Night after Labor Day. 2 right lanes closed first part of evening and then 2 left lanes. Work on the outside edges of overpass. *SD-805/La Jolla Village Drive Project* *Project No. 11-089754*	23:00-23:15 NO CHP 00:00 - 00:45 ECOZEEP #1 00:45 - 01:45 Lane closure moved to other side 02:45 - 03:15 ECOZEEP #2	Yes Qty not logged (1 Log for 3 units)

Approach speed is 67mph Short closure (0.84 mi) with a single point of work at the overpass. In all the tests the CHP units were located in close proximity to each other and the work zone. In this case the CHP and work zone are clearly visible before the 2nd Arrowboard at iCone 431. K-rail is up against the edges of the lanes slows drivers. In this case the lights at the work zone and multiple CHP lights were extremely prominent. The NO CHP test covers a shorter time period than ideal. Speeds are reduced to about 53mph for ECOZEEP.

ICone 428 at -1.03 mi is plotted at -0.6 mi

LEGEND: - iCone - First Arrow board - Lane Closed



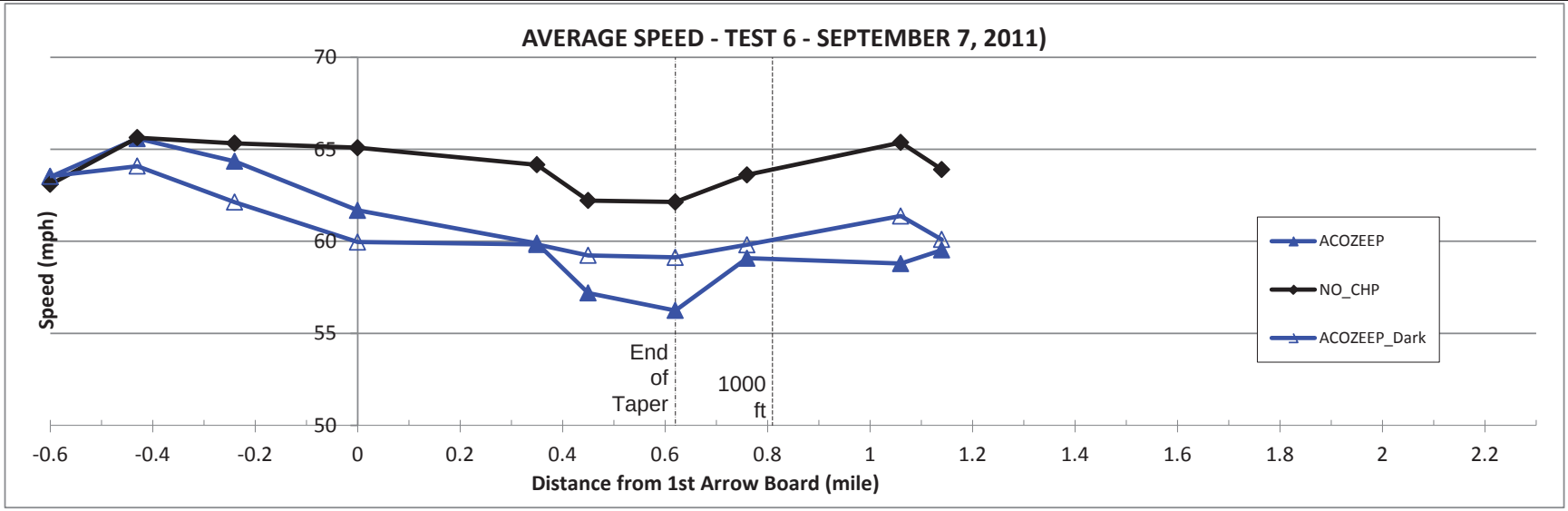
TEST 6 SEPT 7, 2011 - I 805 Northbound - Nobel Dr Exit to La Jolla Village Dr

Description:	**Conditions:**	**CHP Contact:**
Wednesday Night. 2 left lanes closed. Excavator in median loading dump truck loading at Lane #1. Trucks entering and exiting. *SD-805/La Jolla Village Drive Project Project No. 11-089754*	22:00 - 23:30 ECOZEEP #1 23:30 - 00:00 NO CHP 01:30 - 03:00 ECOZEEP #2 Dark	2 verbal, 3 citations Total 5 stops in closure DUI + misc stop out of closure (2 logs)

Similar to Test 3 and 4. Medium length Approach speed 65+ mph. Length is shorter than Test 3 and 4. Speeds are lower. Maybe because the elevation drops only 170' from beginning of lane closure and only 2 lanes are open with narrow shoulders and merging. At iCone 811 the 2nd lane is being taken at a point where traffic is both merging on & off. This may cause the observed dip in speeds through midnight. ECOZEEP first units are just after the lane closure start and then after iCone 812. This also reduces speeds about 5 mph to 58mph. The dip to 56 mph may be due to congestion. Last iCone might capture slower on ramp traffic resulting in unexpected drop in speed.

ICone 431 at -3.03 mi is plotted at -0.6 mi

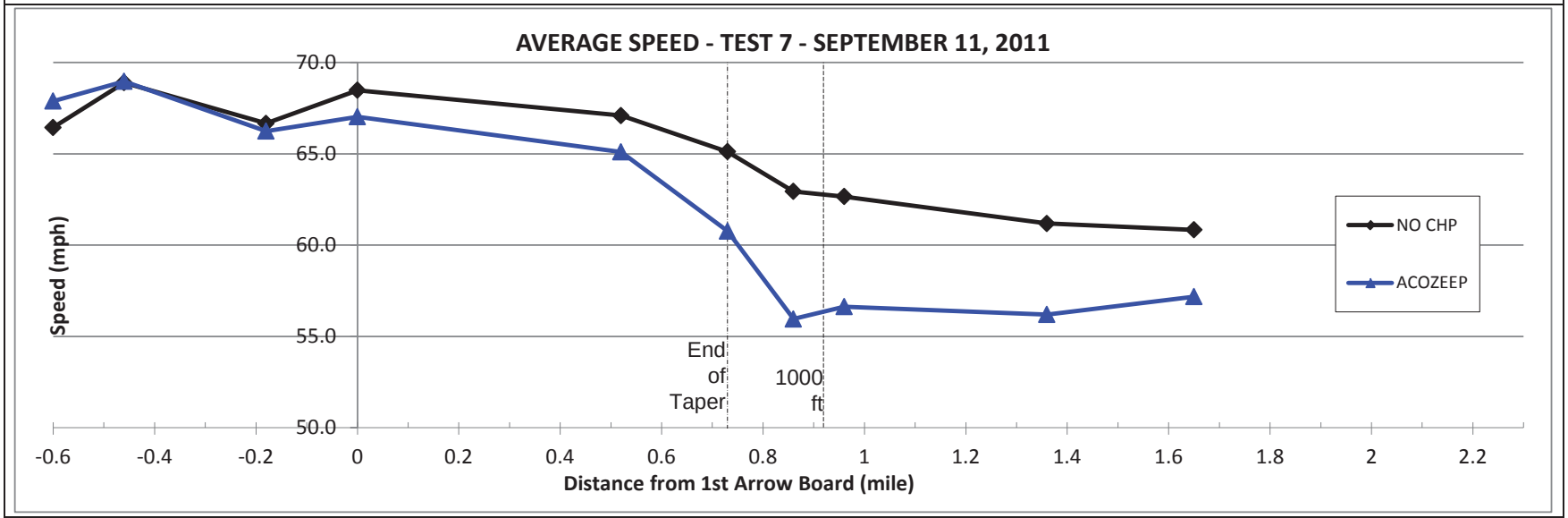
LEGEND: - iCone - First Arrow board - Lane Closed - CHP - Work zone



TEST 7 SEPT 11, 2011 – I 805 Southbound - Before SR52 to Balboa Ave

Description:	**Conditions:**	**CHP Contact:**
Sunday Night. 2 left lanes closed. Work on lanes 1 and 2 repairing concrete. *SD-805 Grinding and Shoulder Rehab Project Project No. 11-2M01704*	23:45 - 01:00 ECOZEEP 01:00 - 01:30 NO CHP	4 verb + 4 cit. + 1 other+ DUI = 10 in closure. 13 Stops total (3 Logs)

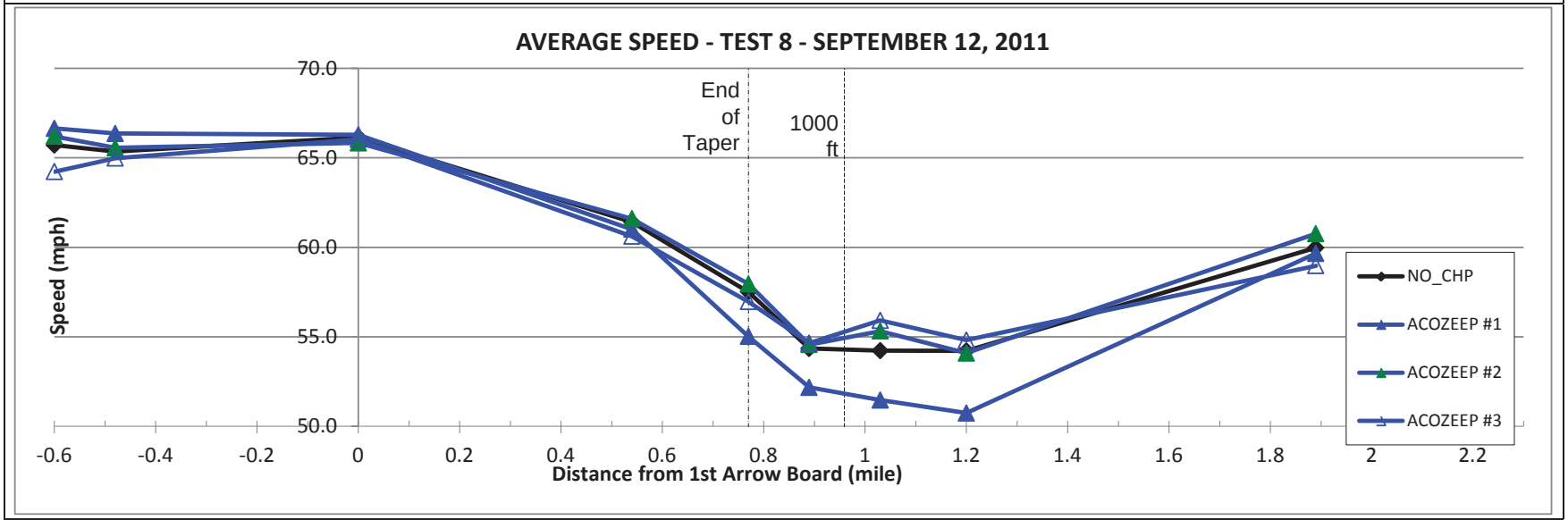
Similar to Test 8. Approach speed is 67+ mph. The closure was long and 2 crews began at iCone 810 and continued to move down the road during the course of the night. The CHP units were clearly visible from before the beginning of the lane closure at iCone 812. The extra CHP units reduced speeds along an additional mile. In this case ECOZEEP reduced speeds by up to 8mph down to 56 mph. ECOZEEP reduces speeds for a longer distance.
ICone 432 at -1.57 mi is plotted at -0.6 mi
LEGEND: - iCone - First Arrow board - Lane Closed - CHP



TEST 8 SEPT 12, 2011 - I 805 Southbound - SR52 to SR 163

Description:	**Conditions:**	**CHP Contact:**
Monday Night. 2 left lanes closed. Work on lanes 1 and 2 repairing concrete. Monitored up to Balboa. Limited work beyond that point. *SD-805 Grinding and Shoulder Rehab Project Project No. 11-2M01704*	21:45 - 22:30 NO CHP 22:30 - 23:30 ECOZEEP #1 00:30 - 01:30 ECOZEEP #2 01:30 - 02:30 ECOZEEP #3	Tested no contact during ECOZEEP (3 logs)

Similar to Test 7. Approach speed is 67 mph. The closure was long and 2 crews began at iCone 430 and continued to move down the road during the course of the night. The CHP units were clearly visible from before the beginning of the lane closure at iCone 812. The NO CHP and ECOZEEP conditions till 23:15 captured reduced speeds due to congestion. During ECOZEEP #3 only 2 CHP were in position. CHP units were always located between iCone 430 and iCone 809. ICone 433 speed could be considered a nominal speed through the work zone since it is located well past the very active work zone and CHP units. A reasonable conclusion is that ECOZEEP reduce speed by ~ 5 mph to 55mph. This is 2 mph less than the previous night.

ICone 431 at -1.84 mi is plotted at -0.6 mi

LEGEND: - iCone - First Arrow board - Lane Closed - CHP