Title

SafeTrip 21 Initiative: Networked Traveler Foresighted Driving Field Experiment Final Report

Permalink

Authors

Nowakowski, Christopher
Gupta, Somak Datta
Sengupta, Raja
et al.

Publication Date

2011-06-01

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

SafeTrip 21 Initiative: Networked Traveler Foresighted Driving Field Experiment Final Report

Christopher Nowakowski, et al.

California PATH Research Report
UCB-ITS-PRR-2011-05

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration.

Final Report for Task Order TA65A0343-15384

June 2011

ISSN 1055-1425

SafeTrip 21 Initiative: Networked Traveler Foresighted Driving Field Experiment Final Report

Primary Author:
Christopher Nowakowski,
Lead Engineer, California PATH

Additional Authors:
Somak Datta Gupta, California PATH
Daniel Vizzini, CEE: Systems
Raja Sengupta, CEE: Systems
Christian Mannasseh, CEE: Systems
John Spring, California PATH
Joel VanderWerf, California PATH
Ashkan Sharafsaleh, California PATH

DISCLAIMER STATEMENT

STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

TR0003 (REV. 10/98)

1. REPORT NUMBER CA4	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER

4. TITLE AND SUBTITLE SafeTrip 21 Initiative: Networked Traveler Foresighted Driving Field Experiment - Final Report	5. REPORT DATE June 2011 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Christopher Nowakowski, Somak Datta Gupta, Daniel Vizzini, Raja Sengupta, Christian Mannasseh, John Spring, Joel VanderWerf, Ashkan Sharafsaleh	8. PERFORMING ORGANIZATION REPORT NO. UCB-ITS-PRR-2011-05
9. PERFORMING ORGANIZATION NAME AND ADDRESS California PATH Program University of California, Berkeley 1357 S.46th St. Richmond, CA 94804	10. WORK UNIT NUMBER 11. CONTRACT OR GRANT NUMBER TA65A0343-15384
12. SPONSORING AGENCY AND ADDRESS California Department of Transportation Division of Research and Innovation, MS-83 1227 O Street; Sacramento CA 95814	13. TYPE OF REPORT AND PERIOD COVERED Final Report June 2011 14. SPONSORING AGENCY CODE

15. SUPPLEMENTAL NOTES

None.

16. ABSTRACT

This report describes the SafeTrip-21, Networked Traveler Foresighted Driving Field Experiment conducted as part of the US DOT's SafeTrip-21 initiative. This experiment developed and evaluated an Advanced Driver Assistance System providing soft-safety or situational awareness alerts regarding "Slow Traffic Ahead" when driving on a freeway. The Networked Traveler system detects slow traffic or queues at several thousand locations in the Bay area, monitors the locations and speeds of its test subjects as they drive, and determines if the driver is approaching the slow traffic fast enough to warrant an alert. If so, the system alerts the driver through an auditory interface. The desired outcome is a foresighted reduction in speed, resulting in a smoother overall transition into the oncoming traffic queue. The system aims to reduce the likelihood of end-of-queue crashes on freeways, this being a subset of the class of rear-end crashes. The hypothesis is tested by computing measures representing the Root Mean Square (RMS) Error of Speed, Peak Deceleration Rate, Mean Deceleration Rate, Deceleration Due to Braking, Pre-Braking Deceleration, and Time before the start of braking. Amongst these, the RMS Error of Speed across all subjects most clearly confirms the test hypothesis -enhanced situational awareness results in smoother driving.

17. KEY WORDS Situational Awareness, Remote Sensing, Driver Behavior, Soft Safety Alerts, Situational Awareness, Freeway End-of-Queue Crashes, Rear-End Collisions, Advanced Traveler Information Systems, ATIS, Real-Time Traffic Information, ITS	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. SECURITY CLASSIFICATION (of this report) Unclassified	20. NUMBER OF PAGES 124	21. PRICE N/A

ABSTRACT

This report describes the SafeTrip-21, Networked Traveler Foresighted Driving Field Experiment conducted as part of the US DOT's SafeTrip-21 initiative. This experiment developed and evaluated an Advanced Driver Assistance System providing soft-safety or situational awareness alerts regarding "Slow Traffic Ahead" when driving on a freeway. The Networked Traveler system detects slow traffic or queues at several thousand locations in the Bay area, monitors the locations and speeds of its test subjects as they drive, and determines if the driver is approaching the slow traffic fast enough to warrant an alert. If so, the system alerts the driver through an auditory interface. The desired outcome is a foresighted reduction in speed, resulting in a smoother overall transition into the oncoming traffic queue. The system aims to reduce the likelihood of end-of-queue crashes on freeways, this being a subset of the class of rear-end crashes. The hypothesis is tested by computing measures representing the Root Mean Square (RMS) Error of Speed, Peak Deceleration Rate, Mean Deceleration Rate, Deceleration Due to Braking, Pre-Braking Deceleration, and Time before the start of braking. Amongst these, the RMS Error of Speed across all subjects most clearly confirms the test hypothesis - enhanced situational awareness results in smoother driving.

Key Words: Situational Awareness, Remote Sensing, Driver Behavior, Soft Safety Alerts, Freeway End-of-Queue Crashes, Rear-End Collisions, Advanced Traveler Information Systems, ATIS, Real-Time Traffic Information, ITS

EXECUTIVE SUMMARY

The Networked Traveler Foresighted Driving Field Experiment has been conducted as part of the US DOT's SafeTrip-21 initiative. In 2007, the US DOT's Research and Innovative Technology Administration (RITA), in partnership with the California Department of Transportation (Caltrans) launched the SafeTrip-21 initiative to both study and demonstrate how current ITS (Intelligent Transportation Systems) solutions could improve transportation safety and reduce congestion using the San Francisco Bay Area as a field test site. This report details one of the projects executed under the SafeTrip-21 initiative, the Networked Traveler Foresighted Driving Field Experiment.

This experiment developed and evaluated an Advanced Driver Assistance System providing soft-safety or situational awareness alerts regarding "Slow Traffic Ahead" when driving on a freeway. The Networked Traveler system detects slow traffic or queues at several thousand locations in the Bay area, monitors the locations and speeds of its test subjects as they drive, and determines if the driver is approaching the slow traffic fast enough to warrant an alert. If so, the system alerts the driver through an auditory interface. The desired outcome is a foresighted reduction in speed, such as taking the foot of the pedal, resulting in a smoother overall transition into the oncoming traffic queue. The system aims to reduce the likelihood of end-of-queue crashes on freeways, this being a subset of the class of rear-end crashes.

The research team identified the extent of the end-of-queue crash problem using data from 1994 to 2006 in the Caltrans Traffic Accident Surveillance and Analysis System (TASAS) database and the California Highway Performance Measurement Systems (PeMS) database. The analysis enabled us to ensure the Networked Traveler System works at all Bay Area locations worthy of special attention in terms of this class of crashes. 13 locations, in particular, were newly instrumented and added by this project to the several thousand freeway locations already covered by our partners. The project also equipped four vehicles, two Nissan Altima's, and 2 Audi A3's, with Alerting and Data Acquisition Systems, for use by the test subjects.

The literature provides three ideas on how the Networked Traveler Foresighted Driving alerting system might reduce end-of-queue, rear-end crashes. First, from the traffic engineering literature, minimizing the speed differentials of the vehicles in the traffic flow may reduce crashes. Second, from naturalistic driving studies, increasing the driver's expectation of a speed change may reduce the chance that the driver will be distracted when encountering the end-of-queue scenario which may result in a reduction in crashes. Third, and finally, from the On-Board Monitoring System literature, there is a notion that smoother driving is associated with lower crash risk, and thus, if the alerting system can influence smoother speed changes, then it may lead to a reduction in crashes. These ideas are quantified by computing measures representing Root Mean Square (RMS) Error of Speed, Peak Deceleration Rate, Mean Deceleration Rate, Deceleration Due to Braking, Pre-Braking Deceleration, and Time before the start of braking.

Of these measures, the RMS Error of Speed confirms the test hypothesis with the greatest statistical significance. The measure captures the variability of speed as a driver approaches a queue. The experiment has a repeated measures design with each subject driving one of test vehicles without alerts for one week and with alerts for the second week. The RMS Error of

Speed across all subjects confirms the test hypothesis - enhanced situational awareness results in smoother driving. Subjects exhibit a smoother approach to traffic queues in the alert week than in the non-alert week. This is heartening because, this measure is closely related to the measure found statistically significant in an earlier evaluation of this concept, but on a smartPhone platform, with an independently chosen pool of 14 subjects. This measure is also most closely related to the standard deviation of speed used in the traffic calming literature, which shows each 1 mph increase in the standard deviation of speed measured at a detector resulting in an 8.4 percent increase in the crash risk. The other five measures computed, also support the test hypothesis but more weakly. The data shows a significant interaction between the measures and the time of day. The alert correlates with smoother driving during morning-commute and off-peak hours. The data shows nothing statistically significant in the evening-commute hours.

The project is grateful to its partners the Metropolitan Transportation Commision, Navteq, and SpeedInfo for freeway traffic data, to the Nissan and Audi corporations for the test cars, and to Caltrans for access to right-of-way.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

The Networked Traveler Foresighted Driving Field Experiment was conducted as part of the US DOT's SafeTrip-21 initiative. In 2007, the US DOT's Research and Innovative Technology Administration (RITA), in partnership with the California Department of Transportation (Caltrans) launched the SafeTrip-21 initiative to both study and demonstrate how current ITS (Intelligent Transportation Systems) solutions could improve transportation safety and reduce congestion using the San Francisco Bay Area as a field test site.

The SafeTrip-21 initiative was managed by RITA's Volpe Center, and the program covered a number of projects that were conducted by the various partners including the Metropolitan Transportation Commission (MTC), the University of California's Partners for Advanced Transportation TecHnology (PATH) and the California Center for Innovative Transportation (CCIT), Nokia, Inc., NAVTEQ, Santa Clara Valley Transportation Authority, and Nissan. The first of these projects was a technology demonstration featured at the 2008 ITS World Congress in New York City where a number of DSRC, WiFi, and cellular based safety and information systems were prototyped and demonstrated (Misener, et al., 2010). After this initial technology demonstration, several of the promising demonstrations were selected to be scaled up and field tested in the San Francisco Bay Area.

This report details only one of the projects that funded under the SafeTrip-21 initiative, the Networked Traveler Foresighted Driving Field Experiment. This experiment was conducted by UC Berkeley's California PATH program in collaboration with researches from Science Applications International Corporation (SAIC) and Delcan Corporation, who served as an independent evaluation team during the course of the study. This report details the work and analysis performed by the researchers at California PATH in collaboration with the professors and students of the U.C. Berkeley Civil and Environmental Engineering Systems Program. Separate reports were produced by the SAIC independent evaluation team (see Jasper, et al., 2010 and Miller, et al., 2011).

The goal of this project is focused on studying the effects of an Advanced Driver Assistance System (ADAS) that provides "soft-safety" or situational awareness alerts regarding "Slow Traffic Ahead" when driving on a freeway. Currently, drivers may receive general traffic information about congestion through the internet, radio broadcasts, or the 511 hotline; however, the information given to drivers is fairly unspecific (such as travel times between two points or incidents along a route), and it is likely to be poorly timed. Drivers may only look at traffic information pre-trip, or they may get updates during their trip every 15 minutes or so, if they are tuned to a local radio station which provides such updates.

In evaluating the current systems for the dissemination of traffic information, it could be argued that there is a large gulf of execution between the needs of the user and the available sources of information. While pre-trip and periodic traffic information might support drivers' strategic decision making, such as affecting their choice of route, this type of information is generally too coarse to affect tactical or operational decisions such as lane selection or choice of speed. However, this gulf of execution is not necessarily due to a lack of available data. Over the past decade, there has been a boom in number of organizations engaged in both the collection, warehousing, and dissemination of real-time traffic information. In the San Francisco Bay Area alone, between the monitoring capabilities of two companies, Navteq and Speedinfo, nearly 5000 sensors exist on the freeway system that can provide traffic speed estimates with latencies that measured in the terms of minutes.

Utilizing the available data that is already collected about the San Francisco Bay Area freeways, combined with the knowledge of an individual vehicle's position and speed, an ITS system was conceived that could provide drivers with real-time, individually tailored, traffic information. Early phases in the planning of this project explored how such a system might best be used to affect driving safety and reduce congestion, and this analysis determined that end-of-queue crashes were a significant problem which could be addressed by such a system. The remainder of the project focused on implementing a Bay Area wide prototype system and testing that system with naïve drivers.

1.2 End-Of-Queue Crash Scenario

1.2.1 Overview

There have been many attempts over the years to examine, understand, and predict crashes, and one common theme among freeway crashes has been in the propensity of rear-end crashes due to the end-of-queue traffic situations. As far back as the 1960's there have been studies that have tried to determine the contribution of speed to likelihood of a crash, and as discussed in the Transportation Research Board's special issue on Managing Speed (1998) these studies have taken two general approaches. First, there is a category of studies that have examined single vehicle speed (or speeding), and second, there is a category of studies that have examined the distribution of speeds in a traffic stream. Based on this latter methodology, the findings of Solomon (1964), Cirillo (1968), Fildes et al. (1991), Stuster and Coffman (1997), and West and Dunn (1971), all point to a U-shaped curve indicating that the incidence of crash involvement increases in proportion to the deviation from the average traffic speed. Thus, as the variability of the speed increases, so does the crash rate.

More recently, Pande and Andel-Aty (2006) applied neural networks to inductor loop and crash data along the Interestate-5 corridor in central Florida to identify situations prone to crash. Their analysis suggested that rear-end collisions occurred in two scenarios. First, they tended to occur in extended stop-and-go traffic, and second, they tended to occur at end-of-queue locations, or locations that had been free-flowing in the 5-10 minutes before the crash.

Pham, Bhaskar, Chung, and Dumont (2010) analyzed Swiss data of four-lane highways using inductor-loop and meteorological data, and random forest modeling to predict incidence of end-of-queue crashes. (An extension of decision tree modeling, random forest modeling aggregates decision-tree models to avoid over-classification.) Traffic scenarios at the study location were categorized along 22 variables including speed, headway, and weather at various sensors along the test site, and the goal was to determine which traffic scenarios were associated with an elevated incidence of rear-end crashes. The study found that the traffic scenarios with the highest rates of rear-end crashes were those of relatively low speed and high flow proceeded by instances of relatively high speed. Furthermore, high variability in the traffic speed in the right lane or between two lanes were found to be the most important factors in determining which traffic scenarios would lead to an increased crash risk. In essence, this study found that the weather was not a large factor in end-of-queue crashes, and minimizing the speed variances both within and across lanes would be the most effective way of reducing end-of-queue crashes.

Going a step further, Zheng, Ahn, and Monsere (2010), correlated the standard deviation of speed measured by in-pavement loop detectors with the resulting crash rates using a case-control design. The study found that each 1 mph increase in this standard deviation of the speed (averaged across the day) resulted in an 8.4 percent increase in the crash risk odds ratio. Thus, on a typical day along the freeway corridor, the standard deviation of speed was about 5 mph, and this corresponded to an odds ratio of 1.49, compared to an ideal day with no speed variance.

One of the goals of the literature review on end-of-queue crashes was to determine a metric or a series of metrics that could be measured during the approach of an individual vehicle into an end-of-queue scenario, such that a change in that metric between the baseline and alert conditions could provide us with evidence of both a change in driver behavior and a reduction in the risk of a rear-end collision. (Baseline conditions served as controls. They were situations that would have warranted an audible alert, but in which no alert sounded so that the effects of alerts could be ascertained.) The breadth of literature described above details the existence of the end-of-queue crash problem and demonstrates that there is some correlation between crash rates and the size of the standard deviation of the speeds in the traffic flow. However, these methods are based on correlating macroscopic traffic flow with the incidence of crashes, and what these studies are lacking is a correlation between the incidence of crashes and the microscopic view of an individual driver controlling an individual vehicle within the traffic flow. While it is understood that rapid changes in freeway speeds leads to an increased incidence of rear-end crashes, what is not well understood is the relationship between crash rates and the actions of individual drivers.

The closest two bodies of literature that has been investigating the linkage between individual vehicle movements and the risk of collision are related to naturalistic driving studies and the subsequent field of On-Board Driver Monitoring Systems (OBMS). Most of our knowledge about crashes has primarily come from after-the-fact analyses based on examining police crash reports and interviews with the drivers and witnesses, but more recently, there exists a movement to try to naturalistically capture and analyze crashes. The 100-Car Naturalistic Driving Study performed by the Virginia Tech Transportation Institute was the first passenger-vehicle study of this kind (Dingus, et al., 2006; Klauer, et al., 2006 and 2010), and this study found that over 93 percent of the rear-end collisions were related to some form of driver distraction. Thus, based on this data, simply informing the drivers of the upcoming speed change might have the effect of reducing rear-end crashes because the drivers will be more attentive after hearing the alert.

Going a step further, as summarized in Misener, Nowakowski, Lu, et al. (2007), OBMS systems were born from the naturalistic observation studies and were originally conceived as a means to reduce crashes in commercial vehicle operations. Later, the concept was expanded and applied to teen drivers (Brovold, Ward, Donath, et al., 2007). The literature in this field has established that aggressive driving, hard accelerations and decelerations, and high-g maneuvers are directly correlated with an individual's crash risk. (See Lotan and Toledo, 2006; Musicant, Lotan, and Toledo, 2007; Toledo, Musicant, and Lotan, 2008, and; Hickman and Hanowski, 2011.) By continuously monitoring driver behavior and providing the driver with feedback, risky driving behaviors could be identified and minimized.

In summary, the literature provides three ideas on how the Networked Traveler Foresighted Driving alerting system might reduce end-of-queue, rear-end crashes. First, from the traffic engineering literature, minimizing the speed differentials of the vehicles in the traffic flow may reduce crashes. Second, from naturalistic driving studies, increasing the driver's expectation of a speed change may reduce the chance that the driver will be distracted when encountering the end-of-queue scenario which may result in a reduction in crashes. Third, and finally, from the OBMS literature, there is a notion that smoother driving is associated with lower crash risk, and thus, if the alerting system can influence smoother speed changes, then it may lead to a reduction in crashes. Each of these approaches is examined in the analysis of the data collected during this study.

1.2.2 San Francisco Bay Area End-of-Queue Analysis

Working with the help of both Caltrans and the MTC (Metropolitan Transportation Commission), the research team examined the crash data for San Francisco Bay Area freeways from 1994 to 2006 using the Caltrans Traffic Accident Surveillance and Analysis System (TASAS) database and the California Highway Performance Measurement Systems (PeMS) database. From this data mining, 13 sites were found worthy of special attention in terms of rear-end crashes. These sites are listed in Table 1.1 and geographically depicted in Figure 1.1. After the sites were identified, detailed field surveys were conducted (see Appendix A) to determine both the site characteristics and the types of countermeasures that might be effective in reducing the crashes at those locations.

Table 1.1: Bay Area Freeway Locations with Elevated End-of-Queue Crash Incidence.

Site No.	Site Location	Site Characteristics	Countermeasures Needed
1	Alameda County SR-13, NB (Post Mile 9.5)	• Limited line of site to sections ahead of curve • Slow queue ahead due to off-ramp backup into mainline	• Slow traffic ahead on right lane due to bottleneck • Slow traffic after curve
2	Alameda County SR-13, SB at Broadway Terrace (Post Mile 9.25)	• Severe fish-hoop off-ramp • Combined with a stop and traffic light at end of ramp	• Curve over-speed • Sensor not needed
3	Alameda County I-880, SB (Post Mile 17.5)	• Combined vertical and horizontal curves • A merge of Oak Street entry ramp and mainline prior to curve • Congestion in rush hours	• Slow traffic after curve
4	Alameda County I-880, NB at SR-238 (Post Mile 19.4)	• Off-tramp bottleneck with backup into right lane of mainline traffic	• Slow traffic ahead on right lane due to bottleneck • Verify sensor locations with SpeedInfo
5	San Francisco County I-280, NB at Geneva (Post Mile 1.5)	• Off-ramp bottleneck with backup into right lane of mainline traffic	• Slow traffic at end of off-ramp • Sensor to monitor second half of off-ramp

6	SR101 NB at Mission/Dubose (Post Mile 4.2)	• Traffic backing up in the off ramp. • Congestion	• Slow traffic at end of off-ramp • Sensor to monitor second half of off-ramp
7	San Francisco County US-101, SB and NB, aka, Hospital Curve (Post Mile 4-6)	• Combined vertical and horizontal curves • Congestion bottleneck • Traffic Weaving with on- and off-ramp traffic	• Slow queue ahead • Verify sensor locations with SpeedInfo
8	Santa Clara County I-880, NB at US-101 (Post Mile 4.2)	• Frequent collisions with K-rail barrier on left side	• Curve Over-speed • Sensor not needed
9	Santa Clara County US-101, SB between Tully Rd and Story Rd (Post Mile 32.9)	• Considerable traffic weaving between two exits in congestion periods	• Traffic Weaving potentially on the two outside lanes • Verify sensor locations with SpeedInfo
10	Santa Clara County US-101, NB near Cochrane Interchange (Post Mile 18.0)	• Near 60% of collisions on left lane • Near Transition of 3-Lane into 4-lane segment with HOV lane on left • On-ramp and off-ramp nearby	• Lane Transition Traffic Weaving • Problems potentially on the two inside lanes • Verify sensor locations with SpeedInfo
11	Santa Clara County US-101, SB at Tully Rd	• Speeding a major factor (more than 75%) • Rear-end Collision dominate (near 90%) • More than 85% ramp collisions at ramp exit and cross street	• Slow queue ahead • Ramp over-speeding (clover-leaf type off-ramp) • Sensor to monitor the ending portion of the off-ramp
12	Santa Clara County I-280, NB at Wolfe Road	• Limited line of sight to ramp queue from mainline • Signal controlled cross street at ramp exit • More than 90% ramp collisions at ramp exit and cross street	• Slow queue ahead • Ramp over-speeding • Sensor to monitor the ending section of the ramp
13	Contra Costa County I-80, EB between San Pablo Ave & Solano Ave (Post Mile 3.4)	• Combined vertical and horizontal curves • Congestion bottleneck	• Slow traffic ahead due to bottleneck • Traffic Weaving

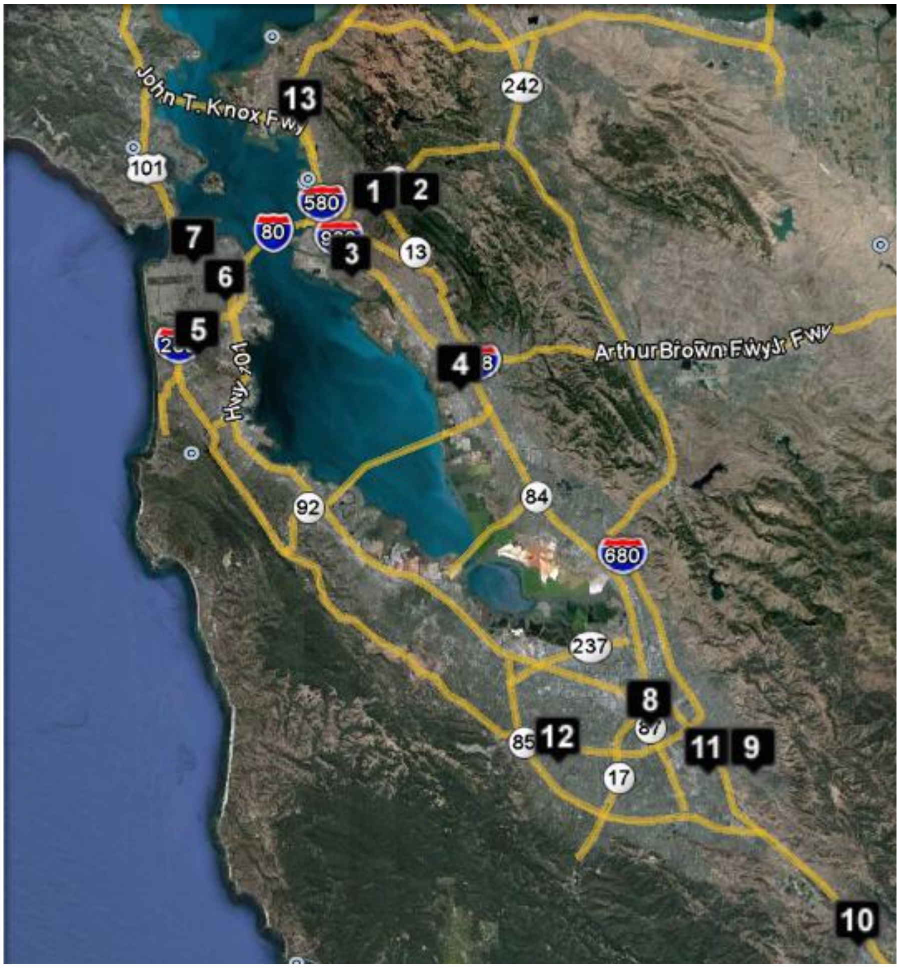


Figure 1.1: Geographical Depiction of Bay Area Locations with Elevated Incidences of End-of-Queue Crashes.

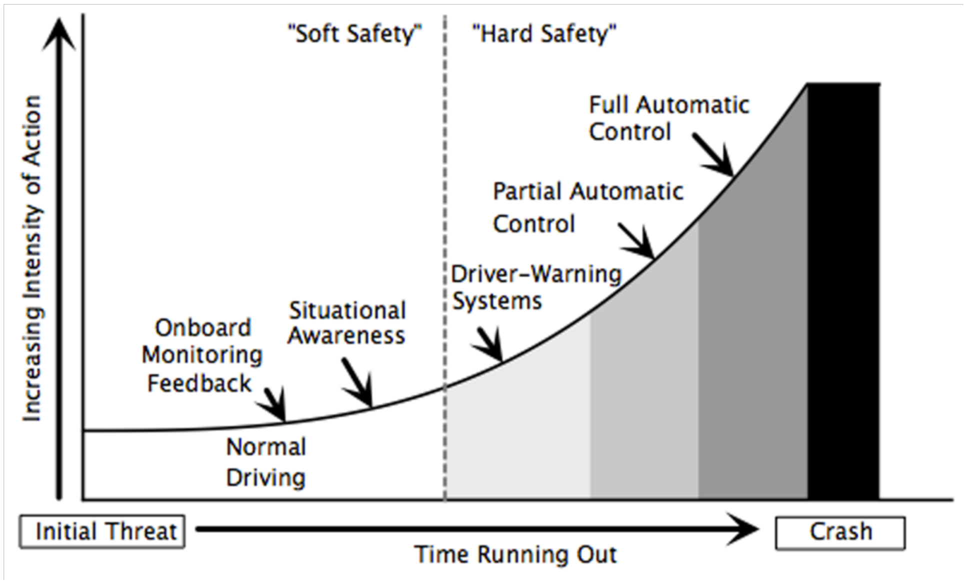
Based on the detailed analyses of the thirteen sites with high incidence of end-of-queue crashes, it was determined that drivers approaching most of the locations could benefit from advanced warnings regarding the slowed or stopped traffic. Many of the locations involved traffic being stopped around blind curves where traffic was entering or exiting the freeway. The prime example is location 7, Hospital Curve along US 101 through San Francisco. This two mile section of curved freeway can, quite frequently, contain traffic backs up that are not visible to approaching traffic due to the curvy nature of the freeway.

While the above analysis focused specifically on physical locations where end-of-queue crashes appeared frequently, the discussions with both Caltrans and the MTC also identified non-recurrent congestion as another cause of end-of-queue crashes, often due to an initial incident. When traffic builds in an unexpected location due to an incident, it often leads to secondary, end-of-queue crashes.

1.3 The Foresighted Driving Solution

1.3.1 Advanced Driver Assistance Systems Overview

The term ADAS (Advanced Driver Assistance System) is used to refer to any number of systems that might be conceived to support the driver in the task of driving. The range of ADAS systems encompass a range of systems from backup cameras to collision avoidance systems. As first discussed in a NHTSA report (1992), crash countermeasures can be plotted along two axes, time and intensity of action required to avoid a crash. (See Figure 1.2.) As time progresses in any driving scenario, the intensity of the action required to prevent a crash quickly increases from actions that can be found in normal driving behavior to actions that are simply beyond human capabilities. This figure has been adapted over time. The situational awareness category was added by Cody (2005), and the onboard monitoring feedback category was added by Misener, Nowakowski, Lu, et al. (2007). In this variant of the graph, we have illustrated a proposed distinction between "hard" and "soft" safety applications.



Source: Figure adapted from National Highway Traffic Safety Administration, 1992.

Figure 1.2: Spectrum of ADAS Applications as a Function of Time and Intensity of Action.

The terms "hard safety" and "soft safety" represent an emerging distinction that is being made in the automotive safety nomenclature between situations that require immediate action and those that do not (Work, Bayen, and Jacobson, 2008; Chan, Manasseh, and Rezaei, 2010; and Manasseh, Fallah, Sengupta, and Misener, 2010). Although there have been no clear definitions published, the term "hard safety" has been used to indicate that an immediate action (within several seconds) is required by the either the driver or the system in order to avoid a crash. Hard safety applications might include forward collision warning systems and road departure warning systems. In contrast, the term "soft safety" has been used to indicate that immediate action is not required by the driver (or system) to prevent a crash. Soft safety ADAS applications can be thought of as providing information that will be relevant to the driver in the range of tens of seconds to tens of minutes from the point of delivery. Essentially, the goal of a soft safety

ADAS application is fairly similar to the goals of most road signs – to provide the driver with preview about the road layout or hazards ahead.

Although some applications may skirt the line between hard and soft safety, one key difference between "hard" and "soft" safety systems is related to the system's designed intent. Hard safety ADAS applications typically provide the driver with a warning that is intended to lead the driver towards a specific action that he or she is currently neglecting. In essence, hard safety systems typically act as a last-second intervention (through warning or automation) to prevent the driver from getting into a crash-imminent situation. Conversely, soft safety ADAS applications provide the driver with information that can be used to make better decisions regarding future events. Soft safety applications provide the driver with enhanced situational awareness, or in the case of the application that is being prototyped and tested in this report, it provides the driver with knowledge of traffic conditions ahead that may or may not be currently visible to the driver.

Finally, over the years, there has been much debate over when to implement partial or fully automatic vehicle control. Some auto manufactures have designed crash mitigation systems which only activate automatic partial braking once a crash imminent situation has been detected. The first example of this type of system was introduced into the North American market in 2004 in the Lexus LS 430's pre-collision system. However, more recently, some manufacturers have been designing collision avoidance systems which engage full braking authority with the intent to stop the vehicle before a crash occurs. One example is the Volvo Collision Warning with Auto Brake (CWAB) system which was introduced as an option on the Volvo S80 and XC70 at the end of 2007. However, in the context of this project, the debate over where to the draw the line on fully automatic control systems is moot, since we are only dealing with an ADAS application that falls further to the left on the graph.

1.3.2 Foresighted Driving ADAS Concept

The experiment that will be described in this report was centered around the testing of a foresighted driving ADAS concept that would utilize currently available traffic information and be capable of providing targeted messages to individual drivers regarding traffic conditions that will soon be encountered. Thus, instead of just telling the driver that there may be congestion on some part of the freeway ahead, the foresighted driving system concept that was developed would provide alerts to those drivers who were rapidly approaching an end-of-queue scenario.

The typical use case scenario that was developed for the foresighted driving ADAS concept starts off with a driver who travelling down a freeway at near free flow speeds of 55 to 65 mph. Unbeknownst to the driver, there is a queue of slowed traffic moving at 25 mph that is building 1 to 2 miles ahead, either due to a bottleneck in the freeway or an incident on the roadway. Furthermore, the end-of-queue may not be immediately visible to the driver due to curves or changes in grade. Without an ADAS system, a driver will continue traveling at their current speed until they notice the end-of-queue ahead, and then they will brake as it becomes necessary, following the trajectory of any cars in front of them and likely propagating any existing braking shock waves. Occasionally, some drivers might be surprised by the end-of-queue, which could lead to hard braking or, in the worst case, a secondary, end-of-queue crash.

Although the main end-of-queue crash problem is essentially a rear-end collision problem, the parameters of the use-case scenario that was laid out above differ slightly from the parameters used in most of the use-case scenarios for vehicle-based forward collision warning systems. Vehicle-based forward collision warning systems employ either a radar or lidar to detect the forward vehicle. These sensors have a limited range, which is a distinct disadvantage when the use case includes a very large speed differential, and like the driver, these sensors cannot see around blind curves. Additionally, many of the systems that rely on radar Doppler effects may find it challenging to detect stopped vehicles, which are a distinct possibility in the end-of-queue crash scenario.

Thus, the conceptualized foresighted driving ADAS would be able to detect the developing end-of-queue scenario at least 60-90 seconds before the driver reaches the end-of-queue, and provide the driver with an informational alert, preventing the potential for being surprised by the end-of-queue and reducing the number of hard braking vehicles near the end-of-queue. The test hypothesis is that the alert might result in "smoother" deceleration. Our analysis uses different metrics of smoothness as discussed earlier. The connection between smoothness and safety is provided by the literature, some of which is summarized in our review.

2 DEVELOPMENT OF THE FORESIGHTED DRIVING ADAS

2.1 Architecture Overview

The Networked Traveler application the software architecture was based on a client-server model. Real-time traffic data from two third party sources (Navteq and SpeedInfo) was aggregated by the California PATH server side process, and used to populate in a database of trigger points along the various San Francisco Bay Area freeways. The information in the database formed the basis for a web-service providing the in-vehicle client with information needed to generate the Networked Traveler Foresighted Driving alerts. The vehicle-based software clients transmitted their current GPS location, and the server responded with a listing of the relevant trigger points that might be along the vehicle's path. The client side application was then responsible for deciding whether or not an audible alert should be given to the driver.

Figure 2.1 illustrates the software architectural overview of the Networked Traveler Foresighted Driving alerting system. Functionally and physically the system was divided into three logical parts. The rightmost section represents the third party real time traffic data feeds which form the basis of the slow-traffic-ahead alerts. The data coming in was filtered and used to populate the respective databases to be used for the web service. The data was logged and archived on a rotational basis.

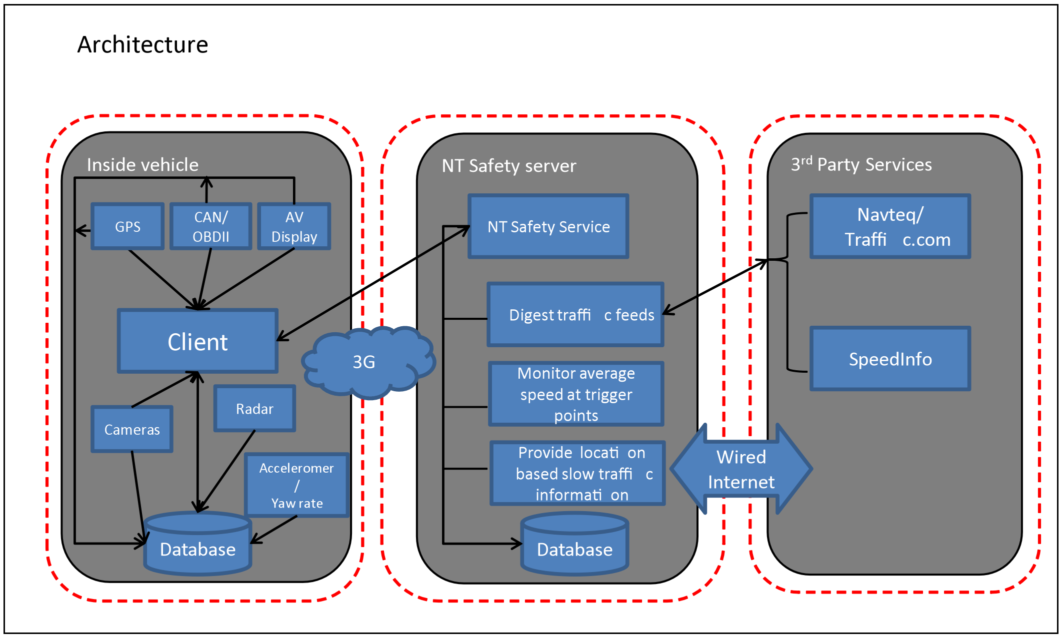


Figure 2.1: Networked Traveler Foresighted Driving Software Architectural Overview.

The middle section represents the Networked Traveler web server and is one of the most critical sections of the system. The primary functions of the section were to digest the traffic feeds from disparate sources, handle incoming client requests and respond to individual responses with current conditions of trigger points around a radius of one mile of the client. To be successful in responding the location based slow-traffic-ahead alert, the server monitors and maintain a database of average traffic speeds at various trigger points for both Navteq and SpeedInfo data. The server also logs and maintains traces of individual users for future post processing.

The system is completed by the third and leftmost section, the client-side application which was running in the vehicles. The client manages array of in vehicle sensors like GPS, CAN/OBDII, radars, accelerometers/yaw rate sensors, cameras, and the audio/video systems. Some of the sensors like the GPS and the CAN provide the real-time information needed to send the server a request for information and to determine whether or not the issuance of a slow-traffic-ahead alert is warranted. Communication between the client and server applications utilized a 3G EVDO cellular modem.

Additionally, there was software verification to ensure that the server responds with relevant information regarding the road condition in a timely manner. There were also sanity checks on the client-side data request to deal with latencies in the cellular network, such that each client request had to reach the server within 60 seconds or it was ignored. The cellular modem was used to keep the client computer systems synched to an NTP server; however, there were occasions where this strategy failed or caused additional data collection problems.

2.2 Networked Traveler Client Application Architecture

In this section Figure 2.2 to Figure 2.4 describe the Networked Traveler client application, with the goal of encapsulating both the application and physical system into one functional diagram. In essence, the client application is not one process, but a set of concurrent processes running on a computer in the vehicle. Each process ran on a configurable update rate, and processes which had similar update rates have been depicted by using the same variable letter in the subsequent figures.

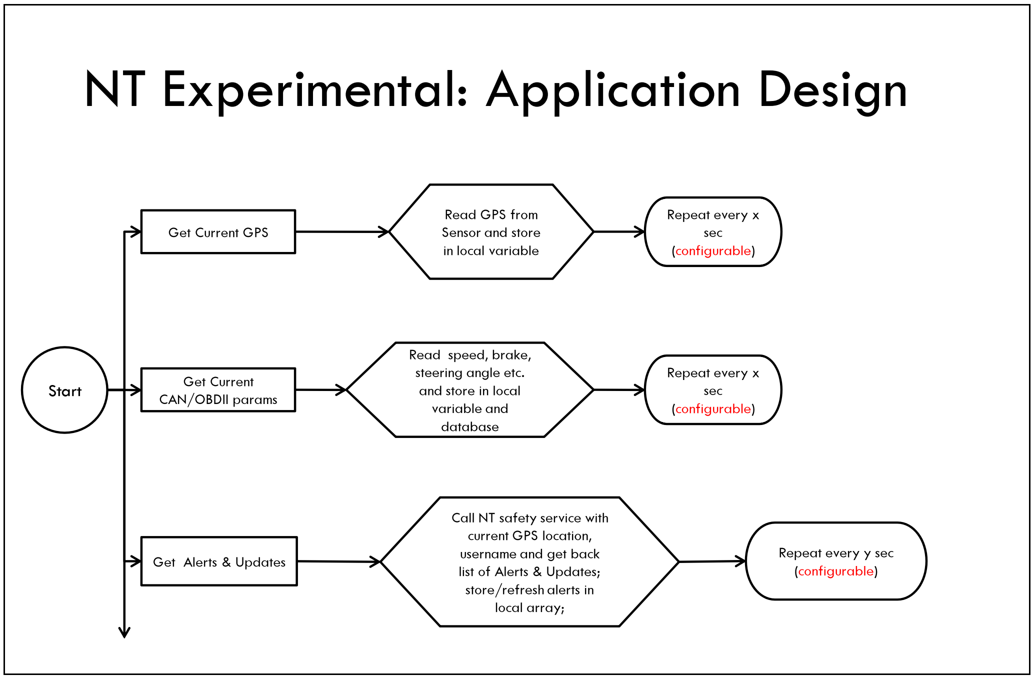


Figure 2.2: Networked Traveler Alert Application Design (Part 1).

<u>*Get GPS*</u>: This process reads from the GPS, parses the GPS sentence and store the values like Vehicle Latitude, Vehicle Longitude, Vehicle Speed (mph), Vehicle Heading (deg), UTC Time, Number of Satellites and Altitude locally every second.

<u>*Get CAN*</u>: This process reads the data from the CAN and populates the data hub in the vehicle. In the Altimas we read parameters like Speed, Brake/Brake Light, Turn Signal, Wiper, Acceleration, Gear, Cruise Control, RPM and Ignition directly from the CAN. For the Audis the parameters were abstracted out via the car gate interface provided by Volkswagen. The parameters read in there included Brake Actuation, Braking Pressure, Lateral Acceleration, Longitudinal Acceleration, Pedal Force, Steering Wheel Angle, Vehicle Speed, Yaw Velocity, Turn Signal Lights, Cruise Control System State, Current Gear, Turn Signal Lever, Wiper Control.

<u>*Get Alerts and Updates*</u>: This process sends the vehicle's GPS parameters to the server (every 15 seconds) and gets an updated trigger point list. The response from the server is further discussed in the server development section.

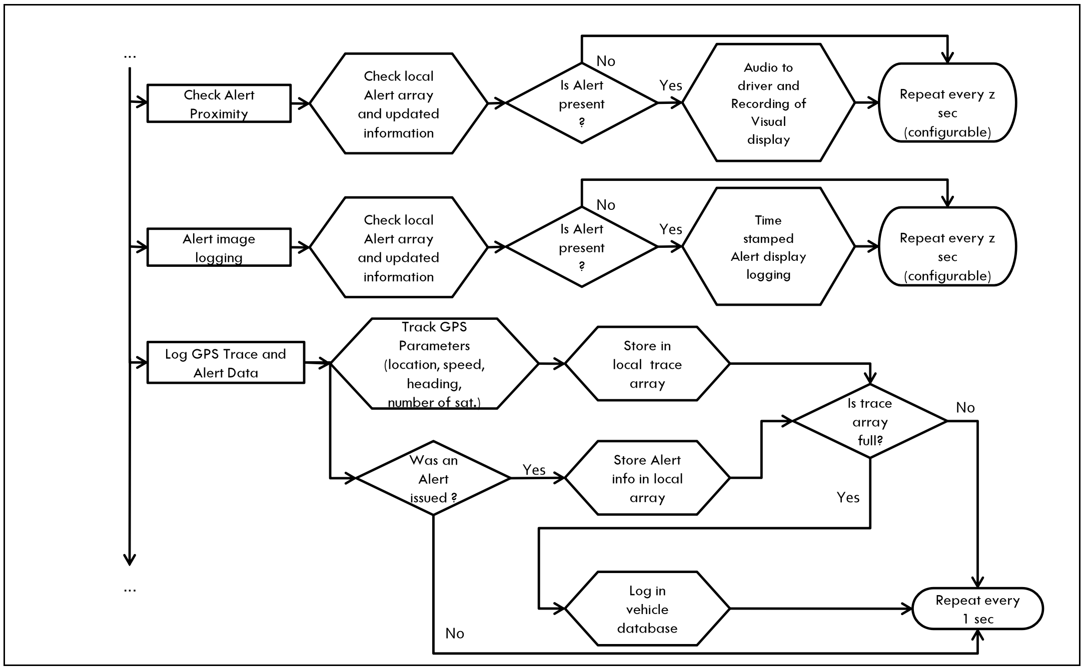


Figure 2.3: Networked Traveler Alert Application Design (Part 2).

<u>*Check Alert Proximity*</u>: This process sorts the list of trigger points returned by the server and by proximity to the vehicle and issues an alert if any of the trigger points meets the alert criterion.

<u>*Alert Image Logging*</u>: As described later in Section 3 of this report, the vehicle Data Acquisition System (DAS) included a video subsystem which recorded graphical representations of the vehicle status (e.g., speed, direction of travel, and presence of an alert condition). The alert image logging process provided the graphical display of the alert to the DAS; however,

as discussed later in Section 2.4.4, the driver-vehicle interface had no graphical display.

Logging: This process logs the periodic vehicle GPS traces, and it logs an alert trace whenever an in-vehicle alert was issued.

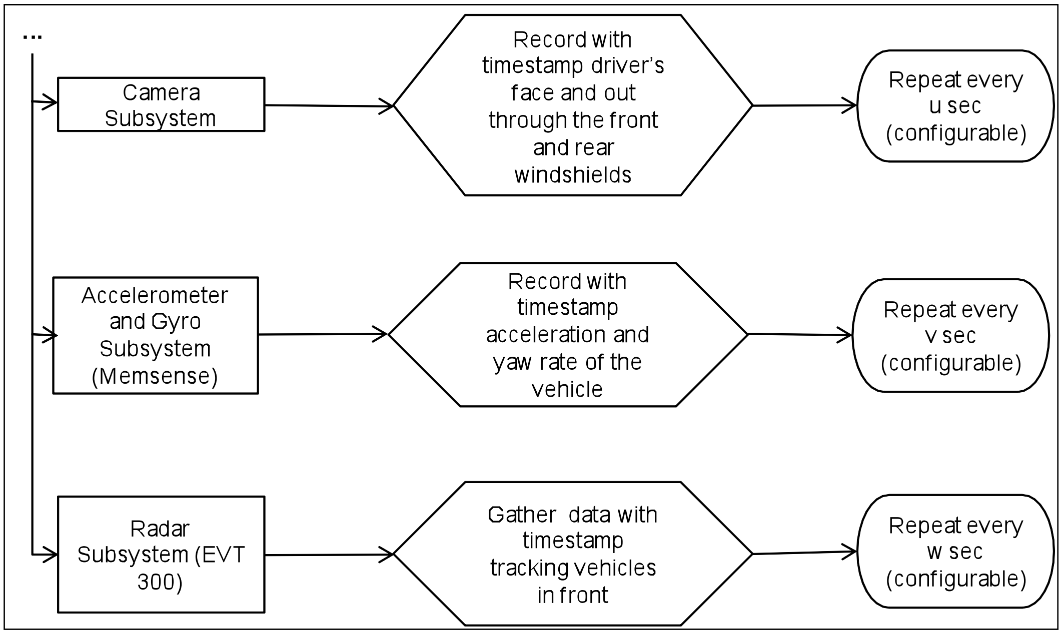


Figure 2.4: Networked Traveler Alert Application Design (Part 3).

The remainder of the processes that were running on the vehicle's client-side computer were primarily concerned with the gathering of vehicle, driving, and video data for the purposes of the experiment. To that end the vehicle was equipped with sensors like radar, accelerometer/yaw rate sensor and a video camera subsystem. These were complemented by a 5Hz GPS and the cellular modem. The vehicle's data gathering and logging systems are discussed in more detail in Section 3 of this report.

2.3 Development of the Server-Side Application

2.3.1 *Traffic Information Feeds*

The server-side application is designed as a web service. There are two main parts of the server application, and the first part dealt with the consumption of real time traffic information from SpeedInfo and Navteq. The SpeedInfo data service is based on the DVSS-100 Doppler radar Speed Sensor system which measures the speed of vehicles on both sides of the highway from a single device. The DVSS-100 sensor is a low maintenance, fully self-contained, solar powered and easily installed unit. The SpeedInfo sensors measures traffic flow at programmable rates continuously. The data gathered from this source is of high quality and low latency.

The second source used for real-time information is a feed from NAVTEQ Traffic. It provides continuously streamed information about traffic conditions. NAVTEQ Traffic contains both traffic flow and incident data, aggregated and tested from multiple sources. Among the data sources are vehicle probes, roadway sensors, and Traffic Management Centers. From our experience, the data from SpeedInfo has lower latency, at least in most of the areas of interest in this study. Additionally, the SpeedInfo data is based on specific sensor points, while the NAVTEQ data is based on a series of freeway links. Thus, in the NAVTEQ data, there is no precise sensor location.

Traffic data from both sources is digested to form a database of Networked Traveler Foresighted Driving trigger points. Each trigger point has a fixed location on the freeway system approximately 60 seconds upstream (at the posted speed limit) from the corresponding sensor location (or the center of the NAVTEQ link). Trigger points are assigned attributes including an id, latitude, longitude, heading, and the measured speed downstream from the trigger point.

Table 2.1 shows how the SpeedInfo sensors are represented in the server. Along with road name and direction they are also associated by their physical lat-long, time of measurement, speed upstream from there, status and lanes covered by the sensor. It is also characterized by the level of confidence of the reading. One shortcoming of this data is that it does not differentiate the HOV lanes from the rest of the lanes. This could result in erroneous alerts for drivers in the HOV lane since those lanes could be faster than the average speed reported by the sensor. This is a known limitation of the system.

Table 2.1: Example SpeedInfo Sensor Representation.

```
id|road_name|road_dir|lat|lng|time|time_epoch|status|confidence|speed|lanes
1331|US-101|N|37.53|-122.274167|2010-10-18 06:15:06.000000-0700|1287407706|OK|100|62|ALL
1332|US-101|S|37.53|-122.274167|2010-10-18 06:15:06.000000-0700|1287407706|OK|100|65|ALL
```

Table 2.2 shows the server representation of the SpeedInfo trigger point. In total there were 607 SpeedInfo triggers in the Bay Area. The figure 2.5 shows the graphical representation of the trigger point and the actual sensor is around 66 seconds downstream from the trigger point. The sensor approximately look 6 seconds upstream in a certain direction so we move the trigger point 60 more seconds upstream so that the alert location is about a minute ahead.

Table 2.2: Example SpeedInfo Trigger Point Database Entry.

```
id|sensor_id|lat|lng|heading|nt_id
1|1331|37.52006|-122.26294|318.171830998281|28414777+
2|1332|37.54573|-122.28918|143.716641724231|28414699-
```

Table 2.3 through Table 2.5 shows the server representation of a NAVTEQ link through the process of converting it to resemble a SpeedInfo trigger point. Since these links were based on Navstreet data, they need some processing. First, the links were converted to nodes so that they would resemble the SpeedInfo sensors. Next, the NAVTEQ nodes were converted into Networked Traveler trigger points. The NAVTEQ trigger points were represented in the same way as the SpeedInfo sensors as is evident in Table 2.5. There are 2792 Networked Traveler trigger points covering the Bay Area based on NAVTEQ link data. As mentioned before we noticed higher latency for the Navteq triggers, introduced most probably in the aggregation and processing of data at their end. To try to combat this, the server-side application attempted to assign a confidence to the readings as a sanity check. In the final analysis, the quality of traffic information provided to the system will directly dictate the quality of the alerts provided to the drivers.

Table 2.3: Example NAVTEQ Link Representation.

```
id|nt_id|ns_id|dir|tmc_id|road_name|road_dir|from_node|to_node|src_node|dst_node|length|fftt|speedlimit
1|23594753-|23594753|-|-105-04568|CA-92|W|65071|65072|65072|65071|0.2397677451|0.261564812836364|55
2|23594767-|23594767|-|-105-04570|CA-92|W|65085|65086|65086|65085|0.087947391|0.0959426083636364|55
3|23600166-|23600166|-|-105N04188|US-101|S|70876|70877|70877|70876|0.1207391471|0.18110872065|40
4|23607387+|23607387|+|+105+04839|I-280|N|76979|76980|76979|76980|0.0434575938|0.0401147019692308|65
```

Table 2.4: Example NAVTEQ Node Representation.

```
id|lat|lng
136|37.22165|-122.40613
137|37.23942|-122.41708
138|37.32446|-122.39993
180|37.10764|-122.29259
```

Table 2.5: Example NAVTEQ Trigger Representation.

```
id|sensor_nt_id|lat|lng|heading|nt_id
1|120905371-|37.30996|-121.88346|147.881009757916|37827725-
2|28411073-|37.30996|-121.88346|147.881009757916|37827725-
```

2.3.2 Server-Side Web Services

The second part of the Networked Traveler Foresighted Driving server-side application is the web service provided to the client vehicles. The web server is capable of handling several hundred simultaneous connections without performance degradation; however, the system was never stressed during the experiment since there were only 4 client vehicles participating in the experiment at any given time. The details of the vehicle requests and server responses are discussed later in the client application section, but generally speaking, the web service returns a list of the most relevant trigger points based on the vehicle's location and heading.

The web server kept a log of both GPS and Alert traces that it received from the client vehicles as described in Table 2.6 and Table 2.7. The trace logs are all related to a particular vehicle, rather than to a particular subject in the experiment. The GPS traces are sent and recorded at 15 second intervals, but the alert traces are only sent and recorded whenever the audible alert was triggered.

Table 2.6: Example Client-Vehicle Alert Trace Saved by the Web Server.

```
AlertID | Day of the Week| Date| Time (PST) | Veh_Lat | Veh_Long | Veh_Speed (m/s) | TimeOnRoad (s) | Trigger_Point_Speed
(mph) | Trigger_Lat | Trigger_Long
734|4|11/17/2010|12:22:56|37.914752|-122.333228|11.883667|8674|6.000000|37.913388|-122.333786
```

Table 2.7: Example Client-Vehicle GPS Trace Saved by the Web Server.

```
Veh_Lat | Veh_Long | Veh_Speed (mph) | Veh_Heading (deg) | UTC_Time | NumSats | Alt (m)
37.9116495| -122.3247335| 35.237| 231.000| 1289361184| 10| 17
```

Additionally, as part of the server-side web service, there are a number of parameters available to the vehicles and web interfaces built for the experimenters that are simply used as a means of controlling the field study experiment. First, there is a web interface that allows an experimenter to remotely configure a vehicle, indicating which subject has possession of the vehicle and whether or not the vehicle should mute alerts (during the first week of the study referred to as the baseline week) or issue audible alerts to the driver (during the second week of the study). Second, the web server made the information in the experiment database available to each of the four client-vehicles so the vehicles could determine on which days the audible alerts should be issued. Third, the web server provides an interface for the participants to log in, view any audible alerts that they may have received, and provide feedback through a short survey (discussed in more detail in Section 3 of this report). Finally, there is an interface created for experimenters to login, view, and download both the alert traces and the feedback entered by the drivers.

2.4 Development of the Client-Side Application

2.4.1 Introduction

The primary safety-related service of the Networked Traveler Foresighted Driving client application is the issuance of audible “Slow Traffic Ahead” alerts for drivers. The client application runs in the test vehicles and performs the following major functions:

- Reads GPS information (position, speed, heading angle, etc) from the various sensors in the car.
- Uploads the GPS samples to Networked Traveler server every few seconds (15 sec, configurable) via an EVDO cellular modem.
- Server searches around the location of the vehicle and if it finds any, sends back relevant trigger points to the client.
- Client uses the server data and if conditions are satisfied, issues a slow traffic ahead audio alert to the driver.
- Once an alert is issued new alerts are not issued within two minutes of the last. The aim is to not bother the driver with too frequent alerts which may occur when consecutive road segments experience slow traffic.
- The vehicle client also logs sensor, GPS trace and alert information for post processing.

The vehicle client constructs the request to be sent to the server from the GPS data. This is the same as the GPS trace logged in the server and consists of vehicle latitude, vehicle longitude, vehicle speed (mph), vehicle heading (deg), UTC time, number of satellites and altitude. Of these the lat-long and UTC time are essential parameters to evoke a server response. Sending the time allows the server to decide on the freshness of the request and act accordingly. Various conditions, usually the occasional communication delay, might cause a request to arrive at the server more than 60 seconds later, in which case the server discards the request as any response to such a request would be too late for practical use. This also necessitates the client server to keep fairly accurate time and hence the client computer clock is synced with NTP at boot.

The following figure 2.5 is an example response from the server in response to a request from user d54cd13QQ16, from lat-long 37.91467905,-122.33391438 and UTC time 1268800100. The vehicle was stationary and could see 6 GPS satellites.

```
[somak@vii ~]$ curl vii.path.berkeley.edu:8082/update/d54cd13QQ16/1268800100?fmt=simple  -d 37.91467905,-122.33391438,0,0,0,6,1268800100
pri 0
display
icon slow.png
sound slow.wav
text slow traffic ahead
trigger
lat 37.900526
spd 58
lng -122.314568
dist 200
hdg 148
dur 90
id 97
stp
pri 0
display
icon slow.png
sound slow.wav
text slow traffic ahead
trigger
lat 37.91142
spd 60
lng -122.32322
dist 200
hdg 325
dur 90
id 99
stp
pri 0
display
icon slow.png
sound slow.wav
text slow traffic ahead
trigger
lat 37.91911
spd 61
lng -122.31736
dist 200
hdg 337
dur 90
id 100
stp
[somak@vii ~]$
```

Figure 2.5: Server Response with a List of Trigger Points.

The server response contains a list of nearby trigger points and values like location, speed, heading, distance and the type of alert associated with each trigger point. The speed is the measured speed of the traffic ahead, and the heading roughly represented the direction of travel of the traffic at that location. Although the trigger point message format included fields for icon, sound, and text, only the field for the sound file was used during this experiment since there was no driver visual display. The server response could also be received in JSON format by changing the “fmt=simple” in the web request to “fmt=json” or not specifying the response format at all since it is the default response.

2.4.2 Alert Logic

The alert logic is described below and also illustrated in Figure 2.6. First, there are some definitions related to the alert logic:

- **Subject vehicle:** Vehicle that its driver is going to receive slow traffic ahead alert.
- **Alert location:** Location ahead of the subject vehicle where traffic is slow.
- **Trigger location:** Represented by GPS lat, long, and heading; about one mile (60 seconds of free flow speed) before the alert location. Alert is issued at or within 0.1mile of the trigger location.

Second, suppose:

- V_s = Speed of the subject vehicle
- V_f = Speed of the vehicles at the alert location

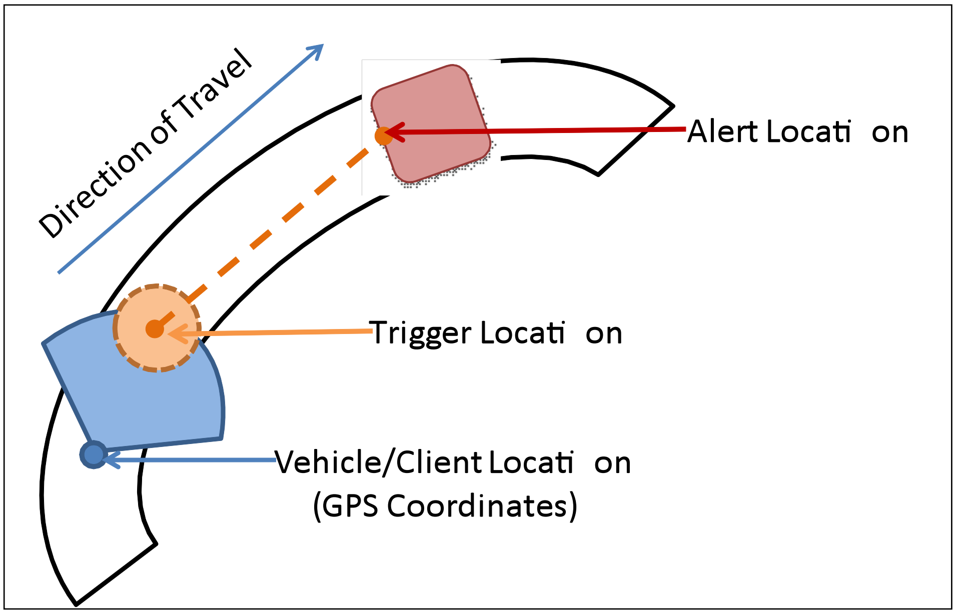


Figure 2.6: Illustration of the Concept Behind the Alert Algorithm.

An alert is issued if all conditions below are satisfied:

1) $V_f \leq 50$ mph
2) $V_s - V_f \geq 15$ mph
3) Distance between trigger location and subject vehicle location ≤ 0.1 mile and
4) Difference between trigger location's heading and vehicle's heading ≤ 50 deg
5) If time between alerts is ≥ 120 seconds
6) If the current date is ≥ Warning Start Date

Also, most of these parameters are tunable and are stored in a file and read in at the start of the application. The parameters and their purpose are listed below in Table 2.8.

Table 2.8: Configurable Parameters Related to the Alert Algorithm.

```
DistToAlertSite=0.1        # miles
HeadingDiff=50.0           # degrees
SpeedDiff=15.0             # mph
TrafficSpeed=50.0          # mph
VehicleNumber=1            # Irrelevant - Handled in alert command line
CurlMaxTime=5              # timeout value given to curl alert request
TimeBetweenAlerts=120      # minimum seconds between audio activations
CurlInterval=15            # seconds between web service accesses
WakeInterval=200           # milliseconds between wake-ups to check GPS
MuteDuration=4             # seconds radio is muted during audio activation
```

2.4.3 Networked Traveler Foresighted Driving System Coverage Area

As discussed in the previous sections, two sources of real-time traffic data are used to generate the Networked Traveler Foresighted Driving trigger point database: NAVTEQ's Traffic.com and SpeedInfo. There were 4242 NAVTEQ sensor locations and 724 SpeedInfo sensor locations, and these translated to 2792 trigger points based on NAVTEQ sensor locations and 607 trigger points based on SpeedInfo sensor locations. All of the trigger points were in the San Francisco Bay Area, and most of the major freeways were covered. (See Figure 2.7 and Figure 2.8.) Some of the trigger points along the freeways were strategically chosen and installed by SpeedInfo specifically for this project to cover a number of locations where there was a high frequency of end-of-queue rear end crashes.

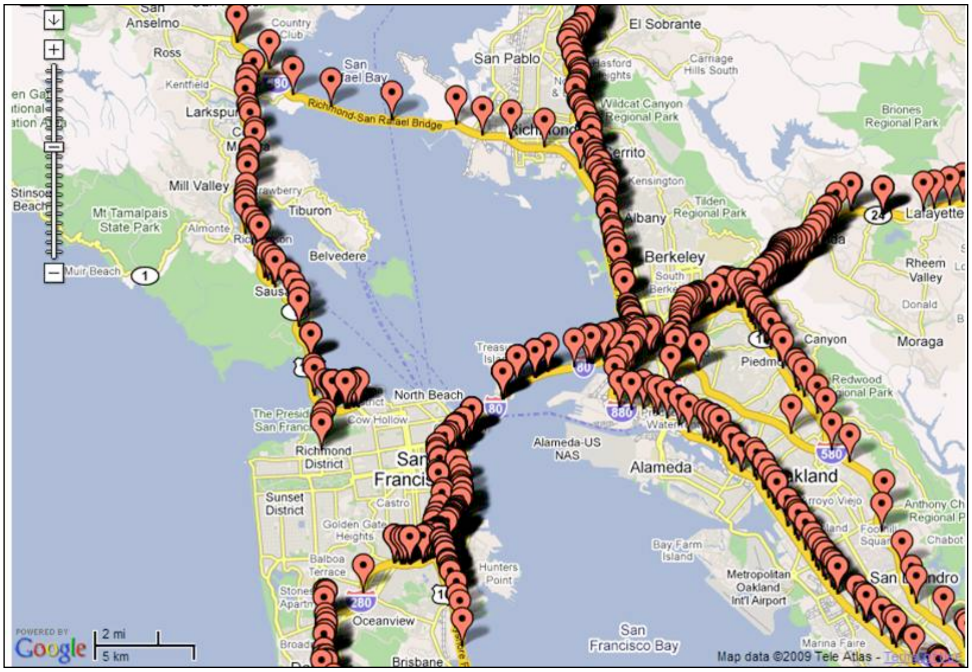


Figure 2.7: Locations with Real-Time Traffic Data Feed (Part 1).

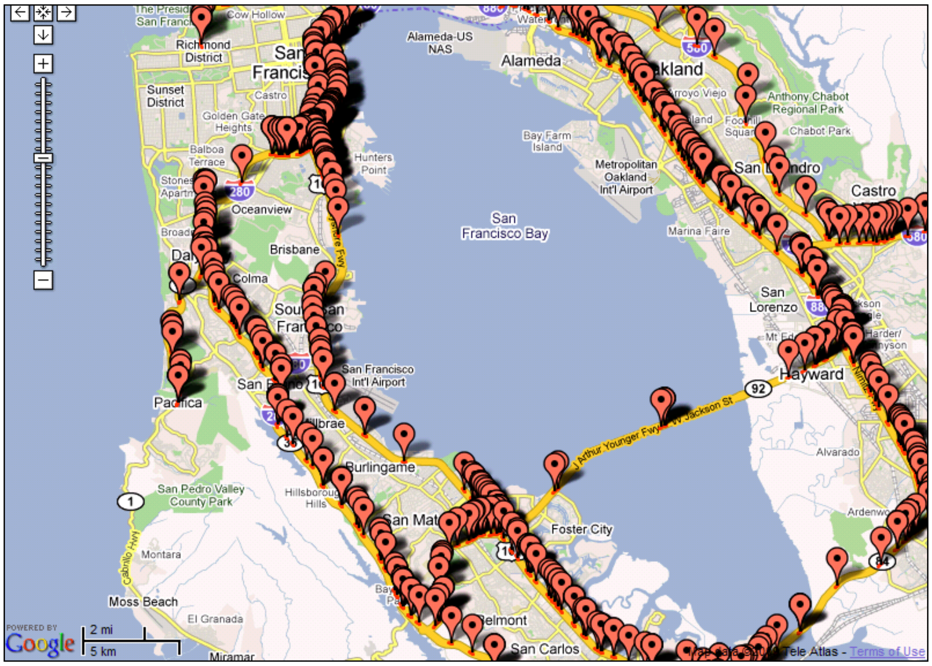


Figure 2.8: Locations with Real-Time Traffic Data Feed (Part 2).

2.4.4 Driver Interface

In the design of the Networked Traveler Foresighted Driving application there are two main components of the driver interface design. The first component of the driver interface design was the selection of an appropriate speed difference threshold (between the vehicle speed and the speed of the traffic ahead), above which, audible alerts would be triggered. This value was chosen to be 15 mph, and decision was based on the literature cited earlier that can be found in the Transportation Research Board's Special Report 254 on Managing Speed. In particular the 15 mph threshold was chosen based the work of West and Dunn (1971) which found that speed differences in excess of 15 mph were associated with increased crash rates.

The second component of the driver interface design addressed what message to communicate to the driver and how best to communicate that message. However, the timing of this project was such that there was growing national concern over the issue of distracted driving. In fact, there were two National Distracted Driving Summits held during the course of this project, in September of both 2009 and 2010. Because of these concerns, the driver interface was limited to the auditory modality, and the message needed to be kept as short and succinct as possible.

Within these constraints, and since a rapid response time is not a consideration, the simplest driver auditory driver interface that could be constructed was the phrase, "Slow Traffic Ahead." In fact, this is the exact wording taken from an MUTCD approved sign warning of the same condition. However, in the pilot testing before the start of the experiment, a number of participants indicated that they also wanted to know some indication of how slow the traffic would be ahead. So, in response to these comments, the system added a target speed of the traffic ahead, rounded to the nearest 5 mph increment. Thus, if the sensor speed of the traffic ahead read 26 mph, then the audible alert would say, “Slow Traffic Ahead. 25 miles per hour.” Furthermore, to increase the likelihood of the driver’s hearing the audible alert, the vehicle’s entertainment sound system was muted whenever an audible alert was issued.

There were also several variants of the audible alert phrase. If the measured traffic speed was below 5 mph, then the alert simply says, “Stopped Traffic Ahead.” Additionally, there were two locations on the San Francisco Bay Bridge where the speed limit was reduced from 50 mph to 35 mph because of a temporary, S-Curve, traffic shift. When approaching these locations, if the vehicle exceeded the 35 mph speed limit, an audible alert sounded saying “Slow Left (or Right) Curve Ahead. 35 miles per hour.” The system architecture permited this to be easily done by adding trigger points with a fixed speed to the database. However, the S-Curve variant of the Networked Traveler Foresighted Driving alert was never triggered by any of the participants in the study.

3 DATA COLLECTION, PROCESSING, AND REDUCTION

3.1 Data Collection

3.1.1 Overview

The Networked Traveler Foresighted Driving ADAS utilized a client-server architecture. In this case, the clients were four instrumented test vehicles, each containing their own onboard Data Acquisition System (DAS), and the application server was a web server located at the California PATH Richmond Field Station. During the experiment, the instrumented vehicles were driven by the participants, and these vehicles communicated with the application server using cellular modems. Data was continually recorded in both locations, on the vehicle DAS and on the application server, so in effect, there were multiple sources of data being recorded in multiple locations during the experiment. Throughout the experiment, data from the various sources was periodically downloaded to a data repository for long-term data storage, processing, and analysis.

3.1.2 Driver Surveys

As described later in Section 4, the participants were asked to fill out a short, web-based survey for each Networked Traveler foresighted driving alert that they received. The alert traces that were recorded by the Networked Traveler application server were used to provide each participant with a listing of any alerts received by that participant during the study. By clicking on an alert, the participants were able to provide feedback for each alert. This feedback was stored in a database on the application server, and an experimenter could manually create an output file for each participant from the information stored in the database. These files were then manually merged for all participants, and moved to the data repository for storage and analysis.

The data set resulting from the per-alert surveys is described in Table 3.1. Each table entry (row) was associated with a specific driver and a specific alert ID. The alert ID was the unique number that was assigned to each alert trace as it was received by the Networked Traveler application server. Drivers did not need to rate every alert that they received, and the system allowed drivers to rate an alert more than once. Additionally, when rating an alert, drivers did not need to answer every question in the survey in order to submit the results. Thus, in the ratings portion of the feedback data (columns 3 through 6), a 0 indicated that no response was given to that question. For the checkboxes (columns 8 through 11), the default setting was off, so a coding of 0 could also indicate that the driver skipped the question.

Table 3.1: Data Set Definitions for the Per-Alert Surveys.

Column	Parameter		Format
1	Driver ID		text
2	Alert ID		int
3	Overall alert rating	(1 Good | 2 Neutral | 3 Bad)	0 - 3
4	Alert correctness rating	(1 Agree | 7 Disagree)	0 - 7
5	Alert usefulness rating	(1 Agree | 7 Disagree)	0 - 7
6	Alert timing rating	(1 Too Early | 4 OK | 7 Too Late)	0 - 7
7	Alert increased awareness checkbox		0/1
8	Alert caused me to reduce speed checkbox		0/1
9	Alert caused me to change lanes checkbox		0/1
10	Alert caused me to alert my route checkbox		0/1
11	Alert caused me to change my mode of transit checkbox		0/1
12	Comments detailing alert conditions		Text
13	Other comments		Text

3.1.3 Instrumented Vehicle Data Collection

3.1.3.1 Vehicle DAS Overview

Four instrumented test vehicles were used in this experiment. Two of the test vehicles were 2008 Nissan Altimas, and two of the test vehicles were 2007 Audi A3s. Each vehicle was outfitted with a DAS to record both engineering and video data which could be used to characterize the motions of the vehicles, driver behaviors, and the functioning of Networked Traveler Foresighted Driving alert application. Select vehicle parameters were recorded from vehicle's CAN network, and the vehicles were outfitted with additional sensors such as GPS, and accelerometer/gyro, and a forward-looking radar.

In addition to the engineering data, the vehicle's DAS was capable of recording up to 4 channels of video data. For this experiment, cameras were place to capture the forward and rear driving scenes, and one was placed to capture the driver's face. Audio was not recorded during this experiment. Since the alert that was being tested was only given using audio, the fourth video channel was a graphic representation of the select engineering and experiment data such as vehicle speed, heading, and information about the closest trigger point.

The vehicle DAS was turnkey, recording data from ignition on (with a 1-2 minute delay for the DAS system startup) until ignition off. All cameras and other instrumentation were hidden from the driver's view as best as possible. The only instrumentation that was readily visible to the driver was the camera focused on the driver's face and a small speaker which was used to play the foresighted driving alerts. The only instrumentation that was readily visible from the outside of the vehicle were two small magnetic mount antennas, one for the GPS and one for the cell modem.

3.1.3.2 Vehicle DAS Hardware Architecture

The PATH instrumented vehicle DAS used in this experiment utilized, almost entirely, Commercial Off-The-Shelf (COTS) components. The system contained two computers which were based on the Mini ITX platform. The first computer was used both to generate the Networked Traveler alerts and to record vehicle and sensor data. The second computer was dedicated to video data acquisition. In the two Nissan Altimas, the DAS was located in the trunk, and in the two Audi A3s, the DAS was located on a package shelf that was constructed behind the rear seats, but below the driver's line of sight over the rear seats. In both cases, the DAS was covered by a protective enclosure to prevent participants from accidentally disconnecting any of the DAS components.

The DAS computer gathered data from both the vehicle manufacturer's CAN and from several other sensors that were added to the vehicles to both enhance the quality of vehicle data that could be collected and to provide mobile communication for the Network Traveler application. A complete systems diagram can be found in Figure 3.1. The sensors that were added to the vehicle included the following:

- A CAN to USB converter (used on the Nissan Altimas)
- A CAN to Ethernet converter used on the Audis (a proprietary device on loan from Audi)
- A forward looking Eaton-Vorad 300 Radar
- A 3-axis, MEMSense, Combination Accelerometer and Gyroscope
- A Garmin GPS18x, 5 Hz, D-GPS
- A LandCell-882 3G Wireless Router

Other incidental equipment required by the system included a standard Ethernet switch and a USB Digital Input/Output (DIO) device that was used to mute the vehicle's audio system whenever a Networked Traveler warning was being issued. The Networked Traveler audio alerts were issued through by DAS system through a standard PC speaker mounted on the dashboard.

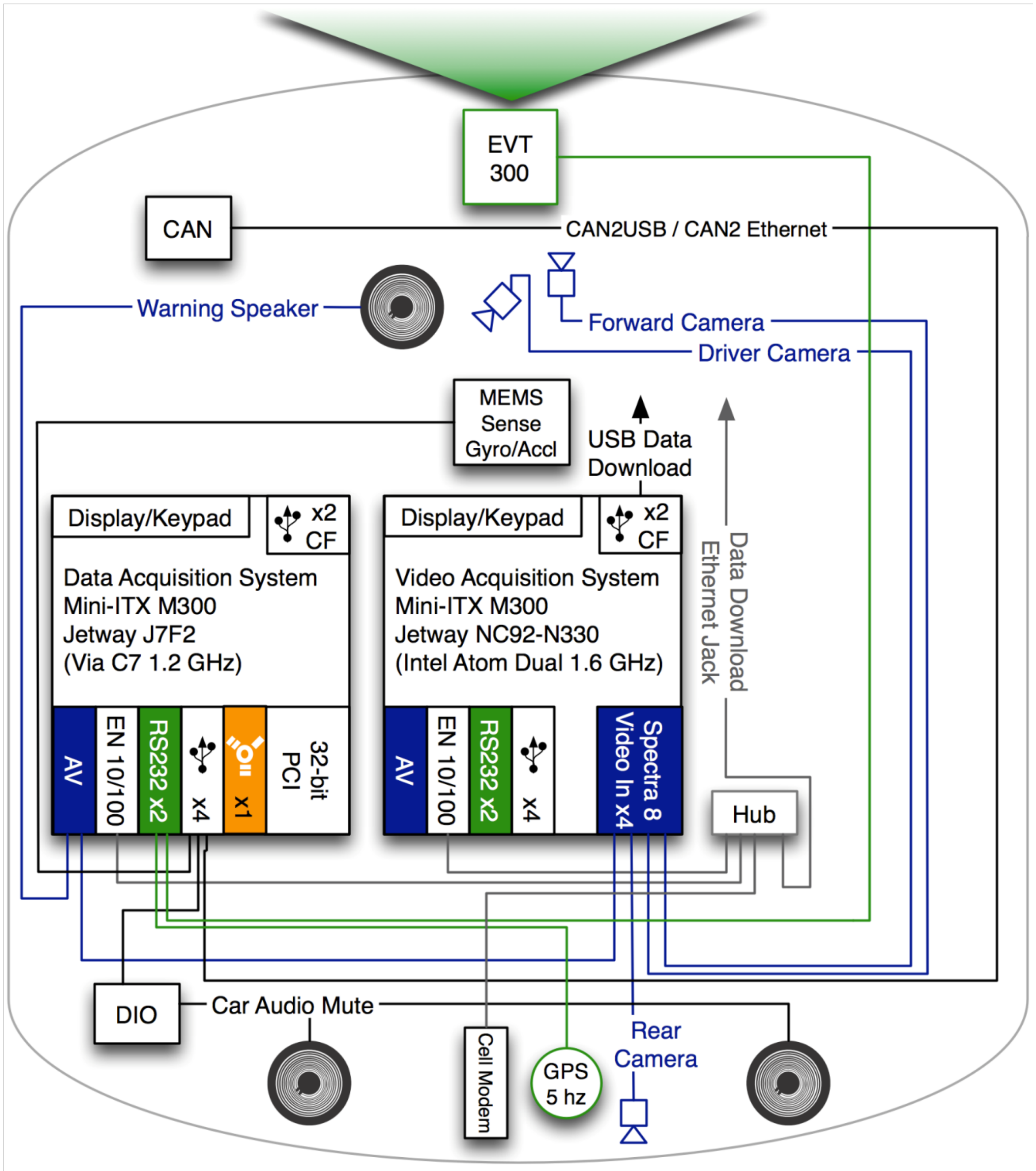


Figure 3.1: California PATH Instrumented Vehicle Systems Diagram.

The VAS (Video Acquisition System) computer could record up to 4 channels of video, each at 320x240 pixels at up to 30 frames per second. For this experiment, three cameras were place to capture the forward and rear driving scenes and the driver's face. Since the alert that was being tested was only given using audio and audio was not recorded during the experiment, the fourth video channel was an experiment status display that was generated by the data acquisition computer (but not shown to the driver). The experiment status display included such parameters as time, date, vehicle speed, and the Networked Traveler alert status. Figure 3.2 depicts an output image as recorded by the video acquisition computer. As shown in this image, a "Slow

Traffic Ahead" alert was currently being given to the driver to warn the driver that the traffic speed ahead was expected to be 40 mph.

Figure 3.2: Video Acquisition System Output Image.

3.1.3.3 Vehicle DAS Software Architecture

The vehicle DAS and VAS software was written in C and C++ and compiled for the Linux operating system. All of the software was custom written by California PATH, but much many parts of the software were based on open source drivers and libraries. Due to the availability of various required hardware drivers, the data acquisition computer ran a version of Slackware Linux and the video acquisition computer ran a version of Debian Linux. The software architecture consists of a set of processes running on the each of the data acquisition computers, communicating through the Publish/Subscribe database. (See Figure 3.3.)

In essence, each process functioned independently. There was a process written for each sensor or device to read the data from that device and place it into the data hub. A communications process would send vehicle position and speed to the Networked Traveler application server over the 3G data modem and write the response from the server to the data hub. An alert process would then read the data gathered by the sensors, determine whether or not an alert condition existed, issue an auditory alert if necessary, and write that information back to the data hub. A display process would then read the data placed into the data hub by the alert process and use it to draw the experiment status screen which was being sent to the video acquisition computer. Finally, a data recording process would write selected data to files.

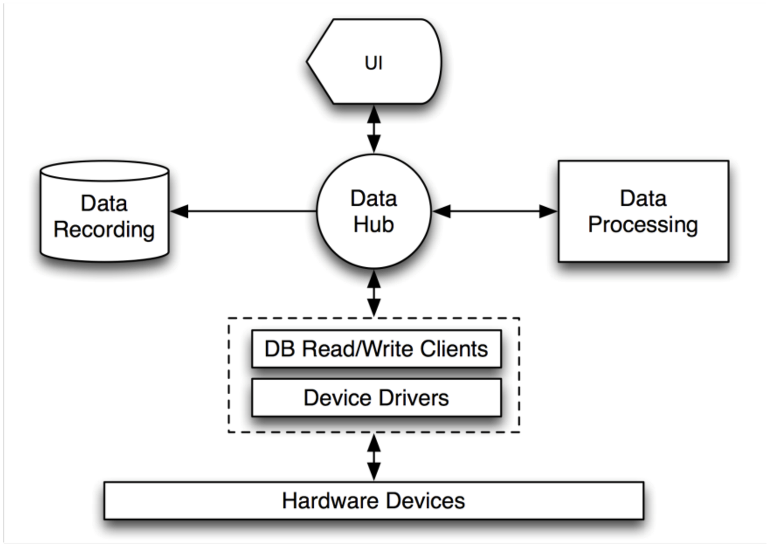


Figure 3.3: California PATH Publish/Subscribe Software Architecture.

3.1.3.4 Engineering and Video Files Recorded by the DAS

The engineering files were recorded and stored locally on data acquisition computer in the vehicle, and video files were recorded and stored locally on the video acquisition computer in the vehicle. The data recording system was turnkey, recording data from ignition on until ignition off; however, it did take the systems anywhere from 60 to 90 seconds to boot up after the ignition on. Each time the DAS started, all of the files recorded were tagged as being part of the same trip. The engineering files were essentially text files containing rows and columns of numeric vehicle data such as speed, distance, latitude, longitude, etc. Data were recorded every 50 ms (20 Hz sampling rate) and new sets of files were started every two minutes.

Three engineering file types were recorded by the DAS, and the parameters recorded by each file type are listed in Appendix B. The engineering “a” file recorded the information gathered from the forward looking Eaton-Vorad 300 radar. The engineering “d” file recorded vehicle or driving data parameters such as vehicle speed and GPS location. The engineering “x” file recorded parameters specific to the Networked Traveler experiment. The “x” file included information on the trigger points sent from the Networked Traveler application server to the vehicle, and it included the status of the Networked Traveler alerts.

As discussed earlier, the DAS could record up to four video inputs. The four video inputs were merged into a single, quad-split, DIVX digital video file recorded at 640x480 pixels using an approximate data rate of 2000 kbps with 30 key frames per second. The files were two minutes long and synchronized with the two-minute engineering data files.

Although it may seem trivial, much effort was put into creating a file naming method that would insure that each file contained a unique name, thus avoiding any potential of accidentally overwriting data when they are copied or moved. The data filenames were constructed using the following convention:

[V][F][MMDD][TTTT][SSS].[EXT]

Where:

- [V] was a single character representing the vehicle on which the data are collected:
    'g' was used for the silver Nissan Altima
    'h' was used for the gray Nissan Altima
    'j' was used for the silver Audi A3
    'k' was used for the red Audi A3
- [F] was a single character representing the type of data that will be contained within the file:
    'a' was used forward radar data
    'd' was used for vehicle-related driving and sensor data
    'x' was used for experiment-related data about traffic conditions ahead and active alerts
    'q' was used for the DIVX video file
- [MMDD] was the date with 2 characters for month and 2 characters for the day of the month
- [TTTT] was a 4-digit Trip ID number which was incremented each time the vehicle is started
- [SSS] was a 3-digit sequence number which starts at 000 and incremented every 2 minutes
- [EXT] was the file extension, either '.dat' for data files or '.mp4' for video files

At the beginning of each new trip, the files from the previous trip were automatically copied into trip directories using the naming convention listed below. The engineering directories were then automatically copied from the data acquisition computer to the video acquisition computer, and the video trip directory was moved into the engineering trip directory.

[F][YYMMDD][TTTT]

where:

- [F] was either 'e' or 'v' indicating engineering or video
- [YYMMDD] is the trip date with 2 digits representing year, month, and day
- [TTTT] is a 4-digit Trip ID which matches the trip ID number of the enclosed files

3.1.3.5 DAS Limitations and Failure Modes

The DAS was designed to be turnkey, requiring no monitoring of or intervention from the test participant. The DAS computers automatically booted up as soon as the vehicle's ignition was turned on, and they automatically shut down when the ignition was turned off. However, there was a delay of between 1 and 2 minutes between the ignition on event and the start of the data recording, so for all of the trips, the first few minutes of the trip were not recorded. In most cases, this resulted in very little data loss, but in some cases, the vehicle may have already entered a freeway by the time the system started to record data. This limitation resulted in 243 trips being recorded by the DAS where the only part of the trip that was recorded was the driver parking and exiting the vehicle. However, since most of these trips were less than 2 minutes in length, these trips were not have been important to the experiment that was being conducted.

There were relatively few DAS failures which resulted in a total loss of all the data for a trip. There were only two recorded instances of DAS failures. Both cases occurred with drivers using the gray Nissan Altima, and it appeared that the data acquisition computer either crashed or shut down prematurely. In one case, the video acquisition computer continued to record video after the data acquisition computer shut down, and in the other case, the video acquisition system shut down at the same time as the data acquisition system. In both cases, the DAS worked properly on the subsequent trip made by the vehicle.

A second limitation of the DAS that could have resulted in total data loss for a trip could result from a participant turning off the ignition, and then rapidly turning the ignition back on. This action had the potential to cause the DAS to miss the ignition-on signal while still attempting to shut down. Participants were warned off this limitation during their orientation; however, the data was not mined to determine whether or not this any trips were lost due to this DAS design limitation.

While the number of DAS failures that resulted in total data loss was few, there were more frequent DAS failure modes which resulted in a partial loss of data during a trip. Most partial losses of data were due to the failures of one or more sensors or cameras failing. Since the time that was allotted in the project to outfit the vehicles was short, there was not time for extensive testing. Several cameras failed during the course of the experiment, but they were replaced within a few days of the vehicles being returned and handed out to the next participant.

Partial data losses generally occurred due to a single sensor process failure on the vehicle or due to failures related to the Networked Traveler application server. First, during the first 4 participants (who were using the Nissan Altima test vehicles), a software bug caused the DAS to fail to record the data that was being gathered from the vehicle's CAN bus on approximately 20 trips (3-8 trips per participant). However, the Networked Traveler alert system still functioned during those trips using the degraded speed information provided by the GPS, so the data gathered was not completely useless. Second, on all of the vehicles, there was an intermittent bug that caused the MEMSense accelerometer and gyroscope to fail on approximately 58 trips or about once per week per vehicle. Again, this failure did not affect the alerts that were being given during the experiment, but they did result in acceleration and yaw rate data being unavailable for those trips. Finally, there were several major outages of the Networked Traveler application server lasting for between a couple of hours to almost a full day. The most serious was on September 17, 2010, where the server was down for a day due to a network issue at the Richmond Field Station. Although the vehicles still recorded driving data during trips taken when the application server was down, no traffic information was being provided to the vehicles during those trips, so no alerts were able to be provided to the test participants.

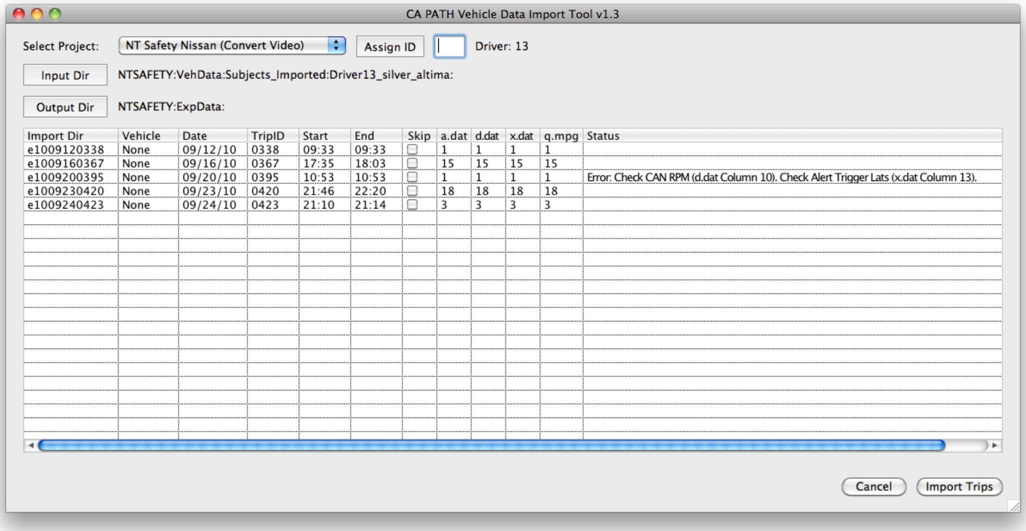
3.2 Data Processing

3.2.1 Data Transfer Process

Each time a new trip was generated on the vehicle's DAS computer systems, the files for the last completed trip were automatically copied to a directory on the DAS video computer and put into a queue to be downloaded. The data remained stored on the vehicles until the vehicles were brought back to California PATH to be readied for the next participant. For each test participant, somewhere between 20 and 50 GB worth of engineering and video data were collected during the 2-week experiment. After a vehicle was returned by a participant, an experimenter needed to manually retrieve the data, verify its integrity, and move it to a server where it could be archived and analyzed. First, the data on the vehicle was transferred to an external disk drive. When an external drive is attached to the video DAS computer via USB, a script could be activated that would copy all of the data in the download queue to the external drive. After the download, a copy of the data remained on the vehicle until it was manually deleted, a process that was done after every few participants. (There were cases where the automatic copying of data failed, and data for some trips needed to be recovered manually.)

The data were then transferred from the mobile disk drive to a data repository server for storage and analysis. The data repository is a raid-array that was attached to a secured computer in a secured room at California PATH. To assist in uploading the vehicle data from the USB drive to the repository, a data importing tool was written in the RealBasic programming language. The data import tool served seven functions (listed below) and a screenshot is provided in Figure 3.4:

1. The tool displays the list of trips recorded by the DAS in a table that can be easily read by an analyst. The analyst can then cross-reference the trips that were downloaded from the vehicles with the dates and times during which the participant had possession of the vehicle.
2. The tool allows the analyst to filter out or skip the importing of inconsequential trips, such as short trips when the vehicle is simply moved, or trips when there was no opportunity for freeway travel.
3. The tool allows the analyst to assign a Driver ID number to the trips.
4. The tool imports (copies) the files from the USB drive to the storage server, while both restructuring and renaming the files to make subsequent data processing easier.
5. During the import process, the tool could also be configured to convert the video from the original DIVX format to a more compact video format. In this experiment, the video was converted to the H.264 .mp4 format at 25 fps, which reduced the video file sizes by 50 percent without a noticeable reduction in the quality.
6. The tool provided the first step in the verification of the integrity of the data being copied by reporting any expected, but missing files, and by checking for potential sensor failures on the vehicles. Missing files would occur in situations where the driver took a long trip, followed by a very short trip. In this case, the automatic copy process would occasionally fail to copy the long trip into the download queue before the vehicle was shut off. When this happened, the missing data was manually retrieved from the copy that remained on the vehicle.
7. The tool created an import log file of all operations performed and errors encountered.



Select Project: NT Safety Nissan (Convert Video)

Driver: 13

NTSAFETY:VehData:Subjects_Imported:Driver13_silver_altima:

NTSAFETY:ExpData:

Import Dir	Vehicle	Date	TripID	Start	End	Skip	a.dat	d.dat	x.dat	q.mpg	Status
e1009120338	None	09/12/10	0338	09:33	09:33	☐	1	1	1	1	
e1009160367	None	09/16/10	0367	17:35	18:03	☐	15	15	15	15	
e1009200395	None	09/20/10	0395	10:53	10:53	☐	1	1	1	1	Error: Check CAN RPM (d.dat Column 10). Check Alert Trigger Lats (x.dat Column 13).
e1009230420	None	09/23/10	0420	21:46	22:20	☐	18	18	18	18	
e1009240423	None	09/24/10	0423	21:10	21:14	☐	3	3	3	3	

Figure 3.4: Sample Screenshot Of The California PATH Data Import And Validation Tool.

After the data were imported to the repository, several backups were made of the data after various steps in the subsequent data processing. First, the data repository storage server used Raid5 technology for fault tolerance against any one disk drive failing. Second, periodic backups were made of all of the project data on the storage server to an external hard disk to guard against more catastrophic failures. The backups contained on the external hard disk were both encrypted and kept in a locked file cabinet with the subject paper records, in order to limit access and protect the confidentiality of the records. Finally, the original, pre-import data remained on the external hard disks until the end of the project.

3.2.2 Data Repository File Organization

While the file naming conventions used on the vehicles were optimized to prevent the possibility of overwriting files due to duplicate file names, the resulting file-naming structure was a bit unwieldy for analysts to visually parse and comprehend. As the files were imported to the data repository, the directory structure and files names were changed to match the following conventions:

- ▼ Driver[XX]
  - ▼ Date[YYMMDD]
    - ▼ Trip[TTTT]
      - ▼ [SSS]
        - [V][F][TTTT][SSS].[EXT]

Where:

- [XX] is a two-digit test participant ID number
- [YYMMDD] is the trip date with 2 digits representing year, month, and day
- [TTTT] is a 4-digit Trip ID number which incremented each time the vehicle was started
- [SSS] is a 3-digit sequence number which started at 000 and incremented every 2 minutes

- [V] is a single character representing the vehicle on which the data is collected.
  'g, h, j, k' as described previously
- [F] is a single character representing the data file type
  'a' is used for forward-looking radar data
  'd' is used for vehicle and vehicle sensor data
  'x' is used experiment-specific data such as alerts
  'q' is used for the file containing the four (quad) video images
- [EXT] is a 3-letter file extension, either .dat or .mp4 for data or video files, respectively.

The resulting file and directory naming conventions allowed analysts to more easily navigate the data and find a particular driver, trip, or video segment. The resulting directory structure also aided in keeping any additional data generated during post-processing organized. As examples, a summary file generated to detail each trip taken by a particular driver would be stored in the driver directory; whereas graphs that were generated to summarize a particular trip were stored in each trip directory.

3.2.3 Initial Automatic Data Processing

After a participant's data were downloaded from the vehicle, validated, and uploaded to a data repository, a number of initial automatic data processing steps were performed. California PATH has a code base of scripts and functions written in the Mathworks MATLAB language to process the data gathered in experiments. However, customization is generally required for each experiment in order to deal with experiment-specific variables and data conversions. Once this customization was completed, an initial analysis was run for each trip of each driver in order to both validate the data and to summarize key trip parameters relevant to this experiment. There were five goals of the initial data processing as listed below:

1. The timestamps recorded in the files were validated, and a best estimate for the synchronization between the DAS system clock and time as obtained by the GPS receiver on the vehicle was computed. Although the vehicle DAS was supposed to synchronize time before the start of data recording, there were times when this was not possible due to a lack of GPS or 3G modem signal. In such cases, manual corrections to the data were required if the clock needed to be reset in the middle of data recording in order to be kept in synch with the Networked Traveler application server.
2. An attempt was made to detect and note all known DAS failure modes; however, when failures were noted, manual inspection of the original data was used to confirm and document the extent of data loss.
3. Graphs of key vehicle and experiment parameters (versus time) were generated for each trip, and a copy of the graph was saved in each trip directory for reference in future analyses. (See Figure 3.5 and Figure 3.6).
4. A Google Earth KML file was generated for each trip from the GPS traces of the vehicles. It overlaid the vehicle route with both the Networked Traveler trigger points passed along the route and the Networked Traveler alerts that were triggered along the route. (See Figure 3.7 and Figure 3.8.)

5. The final output of the initial data processing was a list of all trips taken by all drivers, key parameters from those trips such as trip duration, how many Networked Traveler trigger points were passed during the trip, and how many baseline or audible Networked Traveler alerts were triggered during the trip. This list became the basis for directing future analysis of the data.

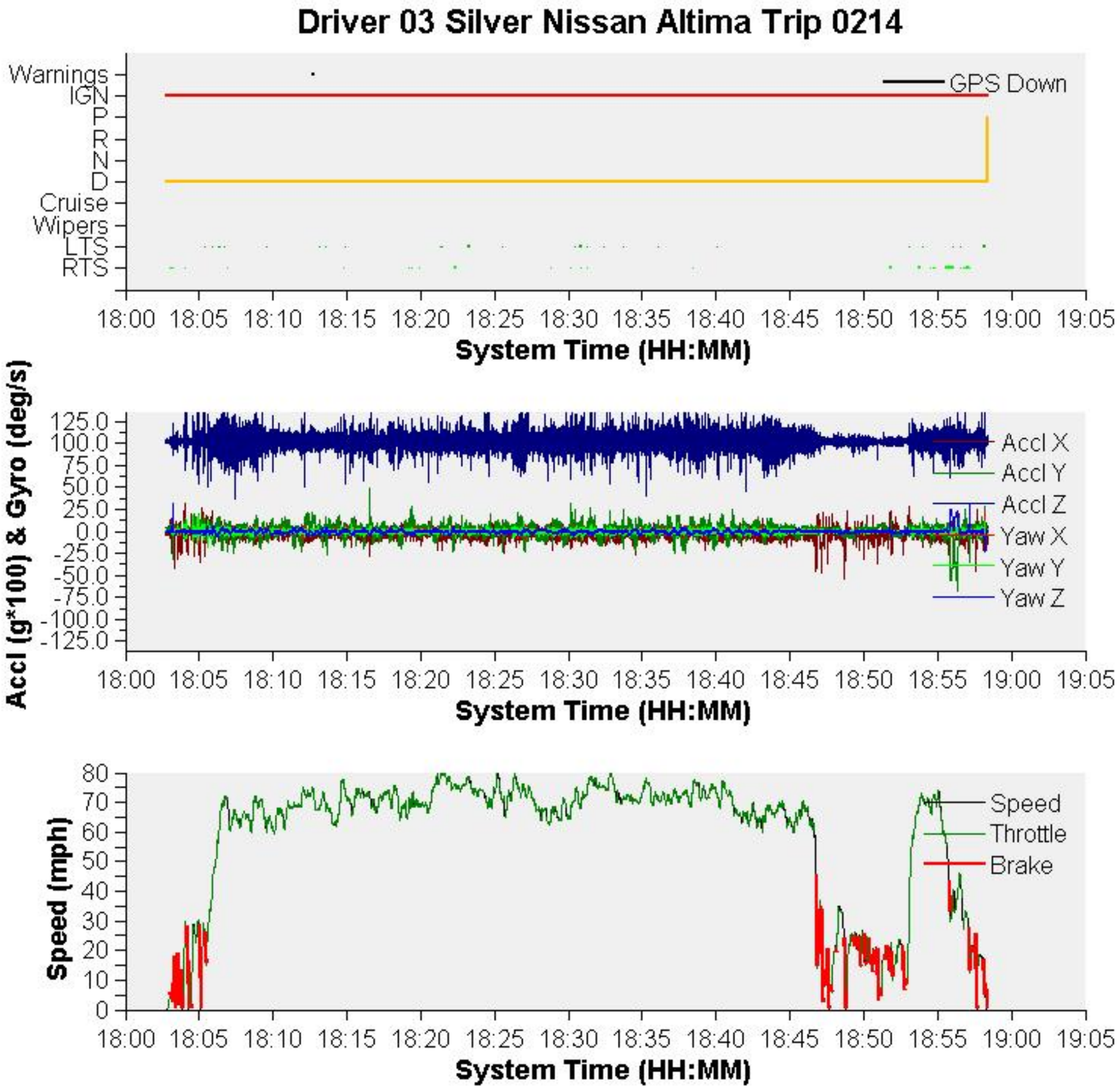


Figure 3.5: Plot Of Key Vehicle Parameters Collected During A Trip.

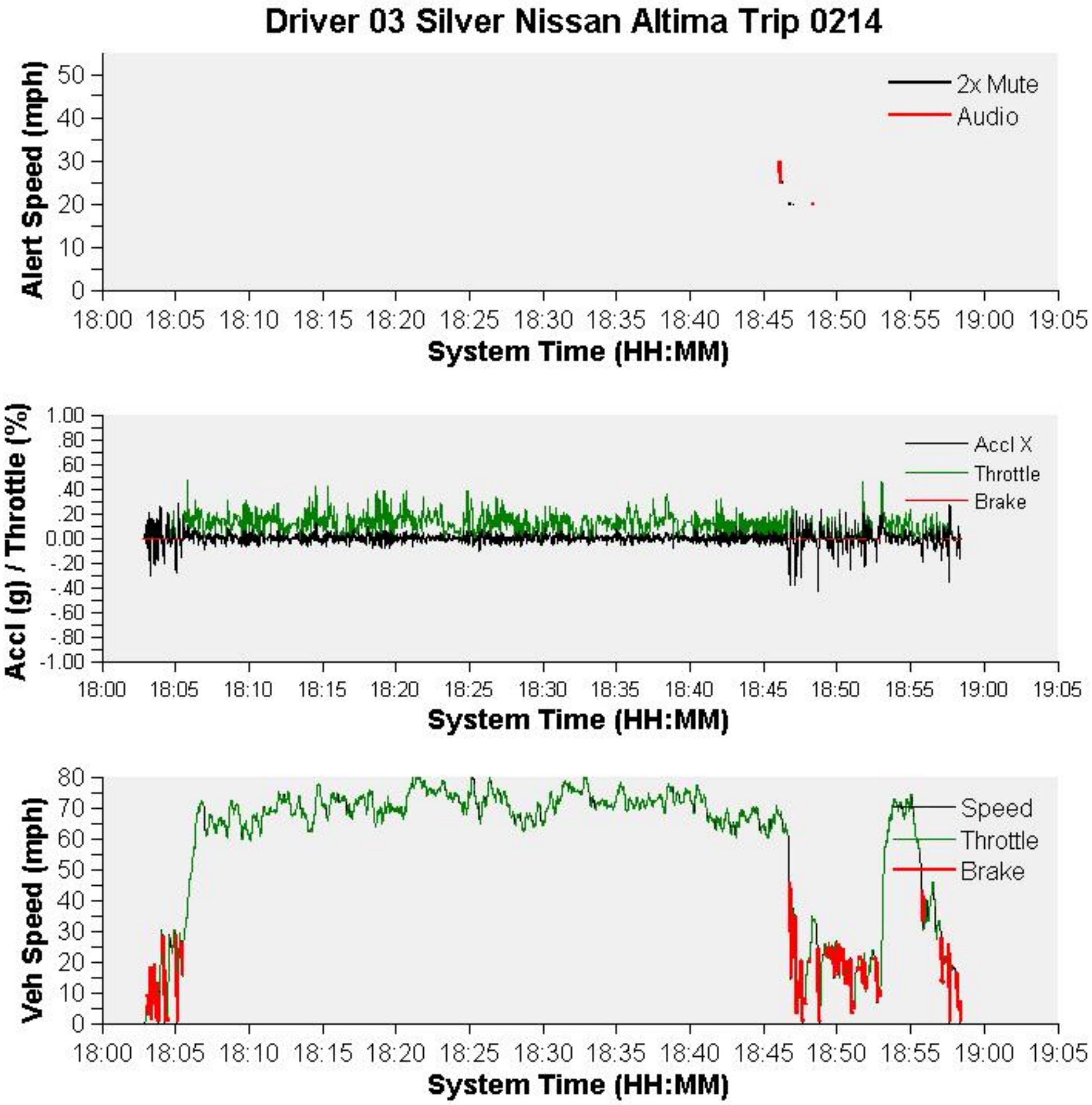


Figure 3.6: Plot of Key Vehicle and Experiment Parameters Collected During a Trip.

Shown below in Figure 3.7, a typical trip of a participant is plotted on Google Earth using the recorded GPS trace of the vehicle. The trip started in San Francisco, CA, and ended in San Jose, CA. The wider yellow line is the route taken by the driver and the call-out bubbles are trigger points passed on the route. Trigger points in green indicated that no alert condition existed when passing that point, while points in red indicated that an audible alert was issued to the driver at that location. Trigger points colored in teal indicate that an alert condition was present while passing that location, but the alert was muted, either because it was a baseline week or because the an audible alert had already been issued in the previous two minutes. On this particular trip, there were actually three audible alerts issued to the driver.

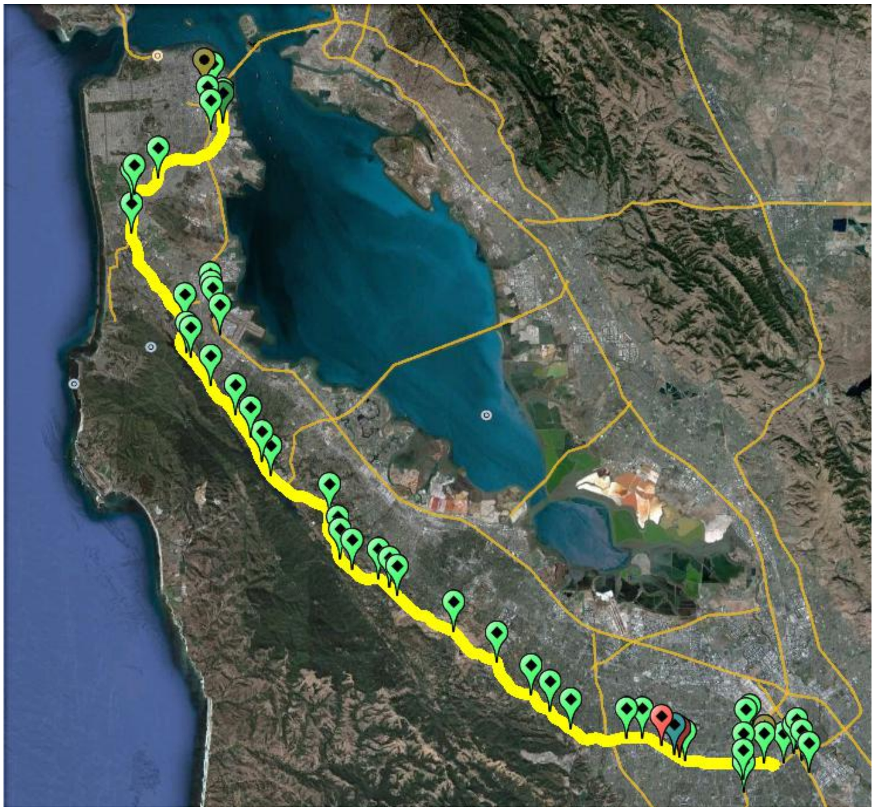


Figure 3.7: Google Earth Plot of a Trip Taken by a Participant.

Figure 3.8 shows the same driver and trip as featured in Figure 3.7, only the map has been zoomed in on an alert sequence that happened as the driver entered San Jose. The driver approached Triggers 1 at 67 mph and, an audible alert was issued to the driver because the sensor speed ahead was reading at 29 mph. Less than 2 minutes later, the driver approached Trigger 2 at 47 mph (sensor speed reading of 22 mph ahead), but an audible alert was not issued to the driver because 2 minutes had not yet elapsed. The driver then approached Trigger 3, 2 minutes and 14 seconds after passing Trigger 1, and a second audible alert was issued to the driver because the vehicle speed was still 35 mph while the sensor speed ahead was reading only 20 mph. Thus, in this case, the driver ended up receiving two alerts for what was likely the same traffic situation simply because of the large spacing between the trigger points and the fact that the traffic slowdown was more gradual than abrupt.

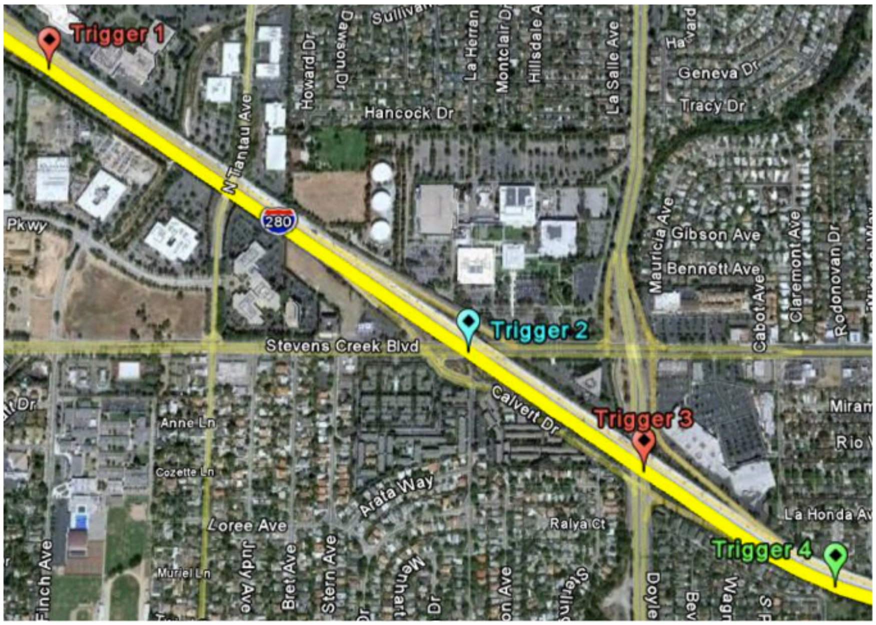


Figure 3.8: Google Earth Plot of Subsequent Alert Locations along a Driver's Route.

3.3 Data Reduction

3.3.1 Alert Counts & Data Source Reconciliation

The first step in the data reduction process involved reconciling the number of audible alerts and driver feedback forms recorded during the experiment. In the experiment, there were two types of alert conditions that occurred, baseline alerts (which were muted) and audible alerts. There were also three sources of data regarding the alerts that were recorded during the experiment. The first source of data was the list of alerts as recorded by the Networked Traveler application server. This list was based on the real-time feedback sent from the vehicles to the server each time an audible alert was issued, and these alert records were used to generate the web interface that allowed participants to later fill out a survey on each alert that they received. The second source of data was the database of per-alert survey responses that was generated on the application server each time the participants filled out the online survey. Finally, the third source came from the data that was continually recorded on the vehicle DAS.

The first issue encountered was that the count of per-alert survey results did not match the count of audible alerts as recorded by the server. In a number of cases, there were more survey feedback results than there were audible alerts recorded. The questionnaire results were first matched with the alerts that were recorded on the Networked Traveler application server, and it was found that there were 37 duplicate entries. The website that participants used to fill out the on-line feedback forms for each alert allowed participants to rate the same alert multiple times. Duplicates feedback forms were manually examined and a determination was made on how to deal with any inconsistencies between the duplicate ratings. In some cases, participants noted that the later entry was the correct rating, but when such information was not available, either the lowest or most neutral value was selected from the duplicate entries.

The second issue encountered was that the list of audible alerts as recorded by the server did not match the list of audible alerts as recorded by the vehicles. We partially reconciled these two lists using the alert date, time, and location. Alerts left unmatched were then examined manually to determine why. Most of the cases where no match was found occur with alerts recorded on the server, but not found when mining the vehicle data. In most of these cases, these alerts have occurred either before the vehicle was handed out to the participant or after the vehicle was returned by the participant. However, in one case, there were several alerts recorded by the server, but not initially found when mining the vehicle data due to an error in the trip file having to do with the vehicle's clock being switched from daylight savings time to standard time in the middle of the trip. Fortunately, we were able to manually reconcile this discrepancy. Finally, there were a few cases where alerts were properly recorded on vehicles, but the feedback message supposed to be sent by the vehicle to the server either failed to trigger or failed to arrive.

3.3.2 Baseline Alert Generation

The third issue encountered had to do with differences between how baseline alert conditions and audible alerts were recorded on the vehicles. When driving during the first week of participation, the DAS recorded all conditions where an audible alert could have been triggered, but during the second week of participation, the audible alert system contained more sophisticated logic to reduce the triggering of multiple audible alerts for the same traffic slowdown. Thus, to reconcile the mismatch, the original algorithm used to generate the audible alerts was recreated and run on the baseline week driving data in a post-processing mode to create a list of locations where audible alerts would have been triggered in the baseline data. This strategy allowed for the most direct comparison between the baseline and the alert conditions.

3.3.3 False Alert Detection

Based on the participant exit interviews as discussed in the report that was generated by the project's independent evaluation team (Jasper, Golembiewski, Armstrong, and Miller, 2010), it was suggested that the Networked Traveler Foresighted Driving alert system was likely to have a very high false alarm rate. Before any statistical analysis on driver response to the system could take place, a methodology for objectively categorizing false alarms needed to be developed. A number of different methods were examined, but the eventual method that was chosen was to examine the time that it took from the point of the audible alert until a point where the vehicle reached the targeted speed of the alert. Per the intended system design, this should have been on the order of 60 to 120 seconds.

The first step in the detection of false alarms was to create a distribution of audible alerts as a function of the time that it took the subject vehicle to reach the alert speed after the audible alert was received by the driver. As shown in Figure 3.9, only 55.4 percent of the audible alerts issued to drivers during the experiment resulted in the vehicle slowing to the targeted alert speed within 2 minutes of the alert being issued. To make sure that the criterion of the subject vehicle actually reaching the alert speed was not skewing the results, distributions were also created for the time to reach within 1 mph and within 5 mph of the alert speed. However, in all three cases, the distributions were almost identical to what is shown in Figure 3.9.

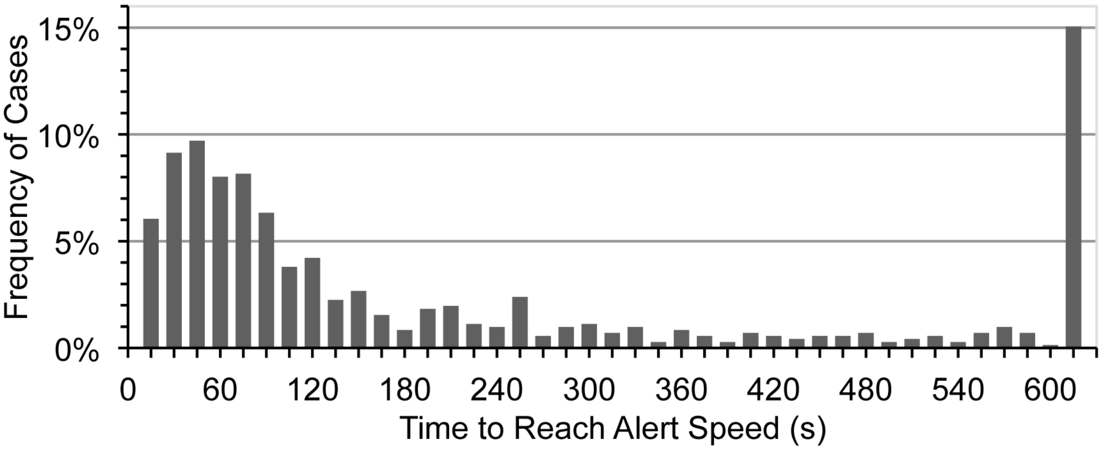


Figure 3.9: Distribution of Alerts by the Time to Reach the Alert Speed.

The second step in process of the false alarm detection was to make a determination of a reasonable cut-off point between valid alerts and false alarms. Random samples of alert cases were taken when the time to reach the alert speed was 180, 240, and 300 seconds (3, 4, and 5 minutes). These random cases were then examined manually by watching the video.

In the random sample, it appeared that for all of the cases when the subject vehicle reached the alert speed within 3 minutes of receiving the alert, both the alert and the driver response appeared to be related to end-of-queue traffic scenarios. In the randomly selected cases where it took the vehicle 4 or 5 minutes to reach the alert speed, the video analysis showed that the vehicle's reduction in speed was not related to an end-of-queue traffic scenario. In most of these cases, the vehicle's speed reduction was related to exiting the freeway.

Based on this preliminary, *a priori,* analysis, the cut-off point for false alarms was set at 180 seconds (3 minutes). This resulted in 62.7 percent of the audible alerts and 68.0 percent of the baseline alerts being included in the final data set.

3.3.4 Selection and Generation of Driver Performance Metrics

The final step of the data reduction phase was to mine the vehicle and alert data in order to generate a data set that could be used in a statistical analysis. The first step in this process was the selection of driver performance metrics which might be used to compare the baseline (non-alert) condition to the audible alert condition. The basic theory behind the Networked Traveler Foresighted Driving alert system was that providing drivers with preview of the upcoming traffic conditions would reduce the surprise of encountered slowed traffic and promote a smoother deceleration profile into the end-of-queue. Along these lines, a number of different driver performance metrics were considered including the following:

- Standard Deviation of Speed
- Root Mean Square (RMS) Error of Speed
- Peak Deceleration Rate
- Mean Deceleration Rate

- Deceleration due to braking (vs. deceleration due to coasting)
- Pre-Braking Deceleration
- Time before the start of braking

Each of these metrics was an attempt to measure and quantify what a smoother deceleration profile might look like. For each metric, a calculation method was written in MatLab, and a script was then used to process each trip containing either baseline or audible alerts, calculating the metric on the section of vehicle data that was of interest to the experiment. For the metrics above, the vehicle data was examined from the time that the alert was issued until the time that the vehicle speed dropped to the reported sensor speed. Using this performance period for each baseline and audible alert event, the driver performance metrics were computed and recorded.

The second step in the data reduction process was to code the potential regression variables that could be used to classify and categorize each baseline or alert event. Thus, each baseline and audible alert event was also coded for driver, driver gender, vehicle, day of the week, time of day, and other potential factors that might explain some of the differences in driver performance that might be seen in the data. The details of these codings vary by the performance metric and are discussed further in the results section of this report.

4 EXPERIMENT PROTOCOL

The experiment protocol, including recruitment materials, consent forms, and test procedures, was reviewed and approved by the U.C. Berkeley Committee for the Protection of Human Subjects (CPHS) prior to the conduct of this experiment. This committee acts as the Institutional Review Board (IRB) for all research involving human subjects at U.C. Berkeley, and it was accredited under the Federalwide Assurance (FWA) program at the time of this experiment.

4.1 Overview

The experiment conducted and described in this report aimed to test whether or not providing drivers with a “Slow Traffic Ahead” alert would influence driving behavior and potentially reduce the probability of an end-of-queue crash. Since crashes are relatively rare events, any hypothesis regarding a reduction in crashes could not be directly tested without both a high market penetration of the foresighted driving application and longitudinal study lasting a number of years. Thus, in this evaluation, surrogate measures of safety needed to be examined. More simply put, the hypothesis of this experiment was that providing drivers with the foresighted driving alerts would alter their driving behavior in some observable way that may allow us to infer a reduced risk of being involved in end-of-queue crash.

Qualifying behavioral changes would primarily include changes the driver’s deceleration or vehicle following profiles. If the alert had a positive effect, we would expect to observe a smoother approach to the slowed traffic. The driver deceleration effect could manifest itself through earlier braking or more gradual deceleration rates. Likewise, vehicle following behavior would be expected to show longer inter-vehicle time gaps being maintained as the drivers approached the slowed or stopped traffic.

4.2 Methodology

There are a number of methods which can be applied to study how drivers may interact with new ITS devices including bench testing, driving simulator studies, on-the-road driving experiments, field operational tests (FOTs), and finally, analyses of post-deployment crash statistics. Each of these methods have both advantages and disadvantages, and some methods are better suited for either earlier or later in the design cycle. The method selected for this study most resembles a small scale FOT. Typically, FOTs recruit somewhere on the order of 100 drivers, giving the study enough statistical power to detect most practical differences that might occur due to between-subjects factors. Additionally, typical FOTs also include testing for extended periods of time in order to examine adaptation effects. This study is both small and short on the FOT scale, but the methodology used is identical to other vehicle-based FOTs such as the Automotive Collision Avoidance System (ACAS) project (NHTSA, 2005) and Integrated Vehicle Based Safety Systems (IVBSS) project (NHTSA, 2008).

The FOT methodology utilizes elements of both an on-the-road experiment and of naturalistic data collection. Similar to a naturalistic data collection, participants were given a vehicle to drive as their own, wherever and whenever they wanted. However, the experiment portion of the study came from the cars being equipped with the Networked Traveler Foresighted Driving

ADAS. In the first week of the experiment, the alerts given to the driver from the ADAS were disabled (muted) in order to gather baseline driving. In the second week of the experiment, the ADAS alerts were enabled, allowing for a comparison of driving behavior both with and without the system. In essence, the methodology used in this study provided for unscripted system testing in the normal context of driving. This was the most important consideration when selecting the methodology for this study.

The main disadvantages of the study design were the short testing duration and the small sample size. With only one week of baseline and one week of testing, it is impossible to say anything about long-term driver acceptance or adaptation to the system. Any shift in driving behavior seen during this study may or may not represent a permanent shift in behavior, and the survey opinions of only 24 drivers may not be a representative sample of the general population of drivers. That said, our sample size is good in the context of the human factor literature.

4.3 Experiment Design

4.3.1 Statistical Design Summary

Any study focused on driving behavior is essentially a study of drivers. From a statistical point of view, it must be recognized that the participants in this study are a sample of the driving population as a whole and that all responses gathered from a single individual are likely to be highly correlated and cannot be treated as independent. Generally, this necessitates the use of a mixed model, repeated measures design.

The repeated measures design distinguishes between two kinds of factors, between-subject factors and within-subject factors. In this study there was nominally one between-subjects factor and one within-subjects factor. The between-subjects factor that was examined was driver gender. In this study each driver saw both baseline (without alert) and alert conditions, so the within-subjects factor (or repeated measure) was the absence or presence of the audible alert provided to the driver by the Networked Traveler Foresighted Driving ADAS.

In many studies, age is also often used as a between-subjects factor. There can be both maturity and driving experience influences when dealing with very young drivers (under 18). Likewise, there can be general performance decrements (such as decreased reaction time) that are typically associated with older drivers (over 65). However, since the Networked Traveler Foresighted Driving ADAS was really targeted towards commuters who are likely to encounter these types of alerts on a daily basis, age was not included as a factor in the experimental design. All of the participants recruited were, effectively, from the same age group.

4.3.2 A Priori *Sample Size Calculations*

In the human factors literature, experiments evaluating human behavior for within-subjects factors using a mixed model or repeated measures design, the sample sizes usually ranges from 16 to 32 participants. This range emerges from a set of statistical methods known as *a priori* power calculations. Sample size is determined as a function of experimental design, desired level of significance (α), and required power ($1 - \beta$). In this calculation, α (usually set to .05) is the prescribed tolerance for false alarms or Type I errors, i.e., the probability that one will reject the null hypothesis when the null hypothesis is actually true. Conversely, β (usually set between .05 and .20) is the prescribed tolerance for missed detections or Type II errors, i.e., the probability that one will accept the null hypothesis when the null hypothesis is actually false.

In order to perform a sample size calculation for this experiment, we used the G*Power3 software package (Faul, et al., 2007) since it can perform a power calculation for a within-subjects effect in a repeated measures design. Once the proper statistical model was selected, the software package required estimates for a number of different parameters related to the both the experimental design and expected outcome of the data. First, the software required an estimate of the number of between-subjects groups (2 in our proposed design, male and female) and the number of measurements expected per participant per treatment. For the number of expected measurements per treatment, we estimated that driver would typically receive around 4 alerts per day for 5 days, and thus, we expected that the average driver would see 20 trials per treatment. Finally, and most importantly, in order to determine a minimum number of participants, all power calculations require an estimate of the size of the effect in comparison to the size of the error. In the G*Power3 software this could be estimated using a Cohen's *f* statistic, and Figure 4.1 shows the relationship between the required number of participants and the estimated size of the within-subjects effect you wish to be able to detect.

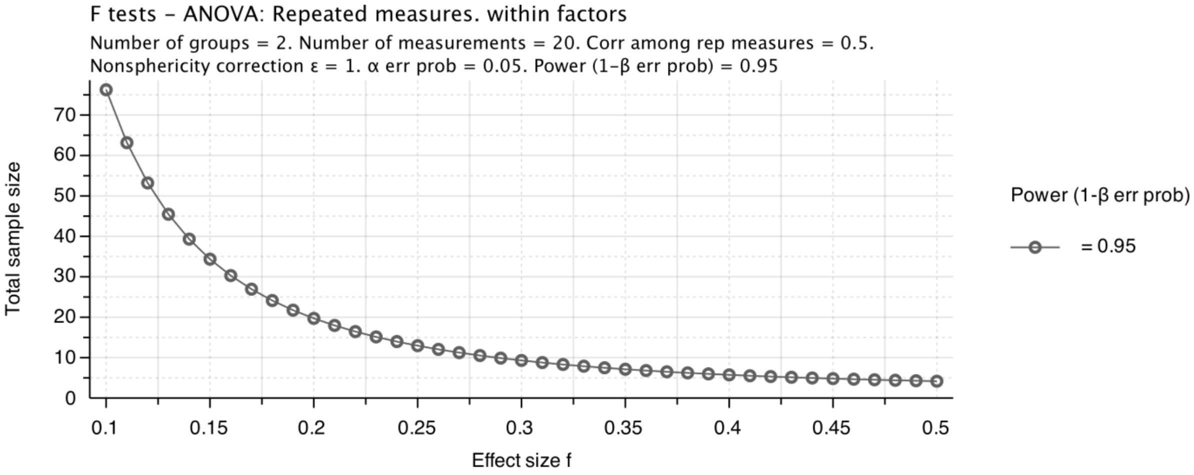


Figure 4.1: Required number of participants as a function of effect size.

Cohen's *f* has been conventionally defined as 0.1, 0.25, and 0.4 for small, medium, and large effects, respectively, and the statistic is defined by the following formula (Cohen, 1988):

$$f^2 = R^2 / (1 - R^2)$$

where R^2 is the coefficient of determination. Typically when using the Cohen's *f* approach, social science researchers select a medium sized effect as their basis for *a priori* power calculations. Based on the formula above, a medium sized effect would correspond to a resulting R^2 of .06, roughly indicating that the effect explained approximately 6 percent of the overall variance in the data. Based on this, a total of 14 participants would be needed. However, to be on the safe side, a total of 24 participants were targeted for the experiment.

4.4 Participants

4.4.1 Eligibility Requirements

To be eligible to participate in this study, potential candidates had to be between the ages of 23 and 65 years old, with a daily commute of at least 15 miles each way utilizing the San Francisco Bay Area freeways that were covered by traffic information feeds that were provided to the Networked Traveler Foresighted Driving ADAS. Additionally, those potential candidates needed to have commutes at times when they are likely to encounter slow or stopped freeway traffic at some point during their commute, which ruled out those with very early or late commutes. These restrictions were set in order to try to recruit participants whose commutes would result into the alert system being triggered at least a few times a day during their daily commute. Potential participants under 23 and over 65 were not likely to have a daily commute, and potential participants who do not commute on freeways or commute at off-peak hours would not encountered situations where the alert system would activate. There were no restrictions based on race or ethnicity; however, the potential participants were required to speak English because the alert system only provided the audible alerts in English.

Potential candidates also needed to meet or agree to the following eligibility restrictions which were put in place by the University of California, Berkeley, Office of Risk Management and the project sponsors, Caltrans and RITA:

1. Participants must have a valid driver's license.
2. Participants must show proof of insurability, e.g., proof of current insurance on their own car.
3. Participants may not have a DUI on their driving record.
4. Participants may not have received a citation for a moving violation in the last three years.
5. Participants may not be currently taking any medications that impair driving.
6. Participants must agree to allow no one else to drive of the research vehicle.
7. Participants must agree to allow only family members as research vehicle passengers.
8. Participants must pledge to abstain from using their personal cell phone while driving while participating in the study.

The last eligibility requirement listed above was requested by the project sponsors. In the state of California, effective January 1, 2009, California SB 28 banned texting while driving and limited cell phone use while driving to hands-free devices only. However, on October 1, 2009, President Barack Obama issued an executive order directing the federal government to take a leadership role in reducing text messaging while driving. Given the current media scrutiny regarding the problem of distracted driving, the project sponsors requested that our participants be informed of the dangers of distracted driving, informed of current cell phone laws, and to pledge to maintaining a standard of behavior during the study that was more stringent than either current federal or state regulations. While the researchers at California PATH feel that this voluntary restriction did not overly influence the results of this experiment, there was the possibility for some self-selection bias towards drivers that might consider themselves more safety conscious. Additionally, this restriction prevents any current or future analysis of the data collected in this experiment from examining the foresighted driving alerting system in the context of a driver being distracted while on a cell phone call.

4.4.2 Recruitment Methods

The test participants were recruited using a number of different methods. First, there was a participant recruitment website that was created (see Appendix C). The website contained a brief description of the experiment and the participation eligibility requirements, a link to the experiment consent form, and a web form where potential participants could submit their contact information to be contacted about the study. When advertisements about the study were then placed on Craigslist.org or through various email lists, those advertisements then referenced the recruitment web page for the study.

Interested candidates were contacted by an experimenter, either by phone or email, in order to verify a candidate's eligibility and gather the necessary information and consent to run a DMV check. DMV records were checked electronically using the Volunteer Select Plus service available from LexusNexis Risk & Information Analytics Group, Inc. Those who passed the screening were scheduled for an experiment session.

4.4.3 Participants

The experiment sample was composed of 24 participants, 12 females and 12 males with ages ranging from 23 to 61, mean of 42 (SD 10.5). As per the study eligibility requirements, all of the participants had a clean driving record for at least 3 years, and none of the participants had a DUI on record. Table 4.1 below details some of the participants' characteristics. The self-estimated annual average mileage of the participants ranged from 10,000 to 30,000 miles per year with a mean of 18,200 mi and a standard deviation of 5000 mi. The mean daily commutes of the participants in the study ranged 25 to 61 minutes with an overall mean of 42.6 (SD 9.2) minutes.

The study ran from July to November, and being the San Francisco Bay Area, weather was not a large factor during this time period. Most of the participants followed the two-week protocol as intended; however, the testing of two of the participants, one male and one female, deviated from the protocol slightly. In the case of male participant, he originally started the protocol in August, but after the week of baseline driving, it was determined that there was a software error with the ADAS system on the vehicle he was driving, and it could not be fixed in the field. Since the participant had not yet seen any of the ADAS alerts, the vehicle was taken out of service and the participant was rescheduled to repeat the entire protocol in a later session. In the case of the female participant, after the baseline week, it was determined that a configuration error had been made with the ADAS system. The error was able to be corrected while the participant was still in possession of the test vehicle, and the baseline week we repeated, followed by the week of ADAS testing. In both cases, the participants simply ended up performing an additional week of baseline driving, and the deviations from the protocol should not have affected the testing outcome.

Table 4.1: Test Participant Characteristics

#	Gender	Age	Est. Annual Mileage	Commute Time (min)	Month of Participation (2010)
1	Male	38	20,000	42	July
2	Female	38	15,000	36	July
3	Male	43	15,000	55	July-August
4	Male	47	25,000	57	July-August
5	Female	35	15,000	25	August
6	Male	49	12,000	46	August
7	Female	52	18,000	48	August-September
8	Female	42	24,000	50	August-September
9	Male	61	25,000	36	September
10	Male	45	12,000	41	September
11	Female	37	10,000	47	September
12	Male	24	--	39	September
13	Female	47	15,000	46	September-October
14	Female	24	15,000	38	September-October
15	Female	23	25,000	50	September-October
16	Female	45	20,000	36	September-October
17	Male	50	15,000	38	October
18	Female	33	20,000	34	October
19	Male	52	15,000	42	October
20	Female	44	15,000	33	October
21	Male	44	18,000	36	October-November
22	Male	49	20,000	30	October-November
23	Female	27	20,000	61	October-November
24	Male	60	30,000	58	October-November

4.5 Test Procedures

4.5.1 Overview

After a potential participant's eligibility was verified through a short phone interview and a DMV records check, he or she was scheduled for an experiment session. Each experiment session was scheduled for a period of two weeks. Although four vehicles were used in the experiment, two of the vehicles were only available for part of the experiment. In the end, there were a total of eight experiment sessions, lasting for a total of 17 weeks. The first four sessions (and the first eight participants) ran with only two vehicles, the two Nissan Altimas, and the second 4 sessions ran with all four vehicles, the two Nissan Altimas and the two Audi A3s. All of the vehicles started an experiment session on the same day. Each experiment session consisted of roughly four phases as described below:

1. Driver orientation session (approximately 2 hours)
2. Baseline driving data (approximately 1 week)
3. Networked Traveler ADAS alert system enabled (approximately 1 week)
4. Driver debriefing session (approximately 2 hours)

The participants picked up the test vehicle from California PATH's Richmond Field Station location during a driver orientation session on the first Saturday morning of the experiment session. They then drove the vehicle as their own for approximately two weeks. During the first week, baseline driving data was collected and the Networked Traveler ADAS alerting system, though active, was muted. Starting on the first trip that began after 12:01 AM on the second Saturday of the experiment session, the Networked Traveler ADAS alert system automatically activated and audible alerts were enabled. Once the participants started receiving audible alerts, they could log onto the study's website and provide feedback on each alert that they received. On the morning of the third Saturday of the experiment session, the participants returned the vehicles to the Richmond Field Station and participated in an exit interview.

As incentive for participation in the experiment, the participants were paid a sum of $100. As further incentive, participants were also reimbursed for any fuel put into the test vehicles during the study, which resulting in an additional incentive of up to $250 per participant. However, in part, the fuel reimbursement was also provided to ensure that there was no cost to the participants for their participation in the study, since some of the test vehicles required premium fuel and may be rated at a lower average fuel economy than the participants' own vehicles.

4.5.2 Participant Orientation

The first part of the study was the driver orientation session, which was held on Saturday mornings at the California PATH Richmond Field Station facility. During the driver orientation session participants were first given a packet of consent materials to review and sign. (See Appendix D.) The packet contained the study consent form, a DMV records check consent form, a video and photographic image authorized usage form, and a fuel card user agreement. The use of a fuel card during the study was optional, but all of the participants opted to sign this agreement. Additionally, although consent for the DMV records check had already been given by phone or email prior to this stage, the DMV records check consent form still needed to be signed by the participant to be in compliance with the records keeping requirements.

After all of the questions were answered and the consent packets were signed, the participants were given brief overview of the project and a demonstration ride in one of the instrumented vehicles. The demonstration ride was given at the Richmond Field Station on a test track where the Networked Traveler "Slow Traffic Ahead" ADAS alerts could be simulated. After seeing how the system works the participants were allowed to ask questions about the system, and the experimenters pointed out all of the vehicle instrumentation and discussed what kinds of parameters were being recorded by the DAS.

Next, the participants were assigned to a specific research vehicle, and an account was created for the participant on the Networked Traveler Slow Traffic Alert Study website which could be used during the second week of the study to rate any alerts that were received. The participant was then scheduled for a half-hour time slot to return the vehicle in two weeks, again on a

Saturday morning. The test vehicles were typically returned to the Richmond Field Station between 8:00 and 11:00 AM, and then handed back out to new participants anytime from 9:00 AM until about 1:00 PM.

In the final part of the driver orientation, one of the researchers performed a vehicle checkout checklist (see Appendix E) with each new participant. The purpose of the vehicle checkout checklist was to help acclimate the participant to the new vehicle. Participants were then given a chance to drive the vehicle around the Richmond Field Station with a researcher present before taking the vehicle home.

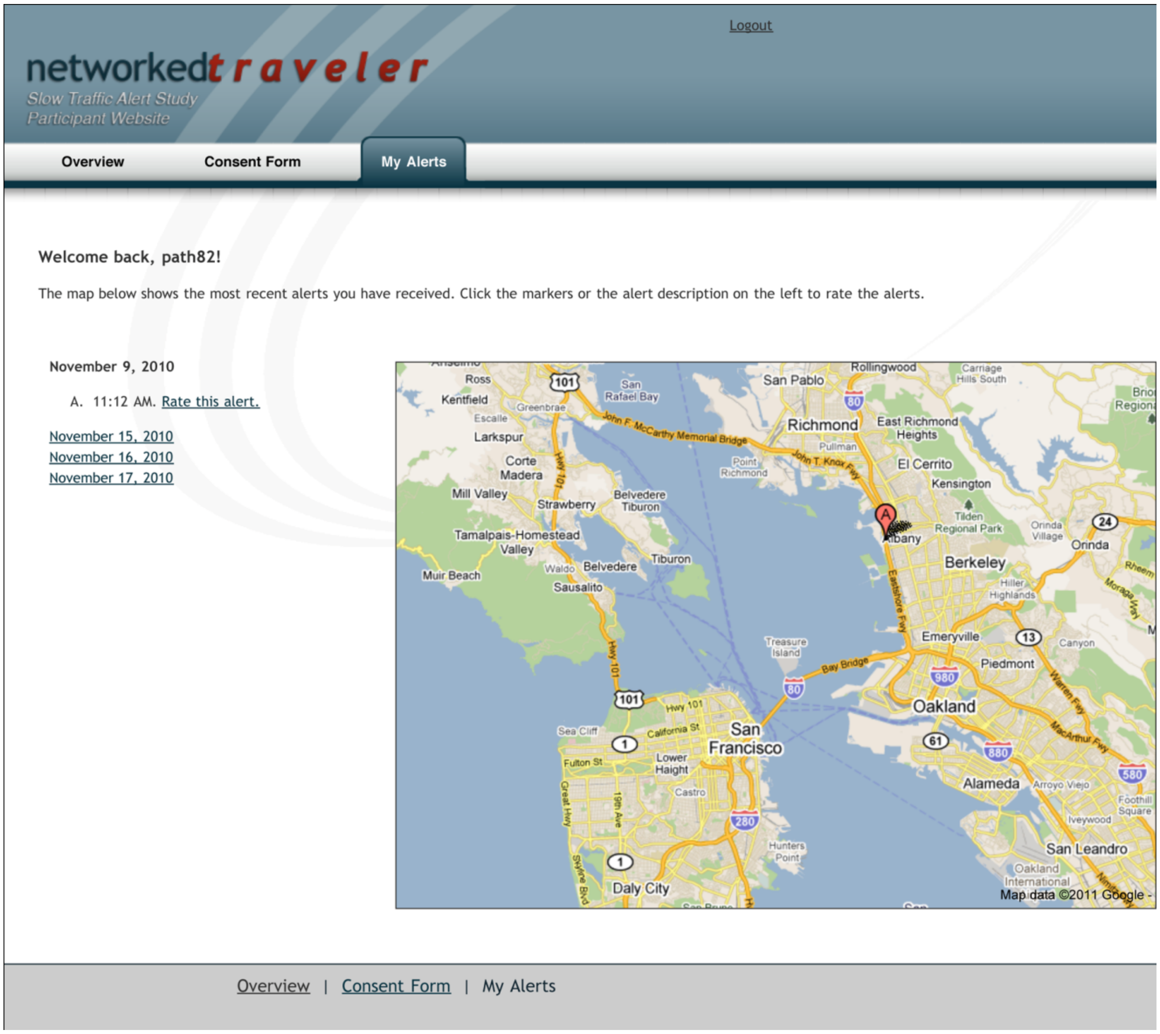
4.5.3 *Baseline Week*

The second part of the study was the collection of baseline driving data. This phase began when the participants drove their assigned test vehicle home from the Richmond Field Station. The baseline data collection lasted for approximately 7 days until the morning of the following Saturday. In the baseline data collection phase, the Networked Traveler alerting system was active and recording data, but audible alerts were not issued to the drivers regarding incidents of slowed traffic ahead. From the participant's point of view, they were just driving the test vehicle as they would drive their normal vehicle for the week; however, this phase of data collection allowed us to measure how drivers normally behave in absence of the new alerting system.

4.5.4 *Alert Week and Online Per Alert Surveys*

In the third part of the study the Networked Traveler "Slow Traffic Ahead" alerting system was enabled, and participants would get an audible alert whenever the system detected that they were approaching slowed or stopped freeway traffic. The system automatically enabled at 12:01 AM on the morning of the second Saturday of the experiment session. As with the baseline week, the participants simply drove the vehicle as they would drive their own vehicle in their daily routine.

Also during this phase of the study, the participants were able to rate and comment on any alerts received through the Networked Traveler Slow Traffic Alert Study website. (See Figure 4.2.) The website could not be accessed from mobile devices, so the participants were not rating the alerts in real time. Most of the participants logged onto to the website every few days to rate alerts, although some only logged onto the website once at the end of the study to rate alerts.



Welcome back, path82!

The map below shows the most recent alerts you have received. Click the markers or the alert description on the left to rate the alerts.

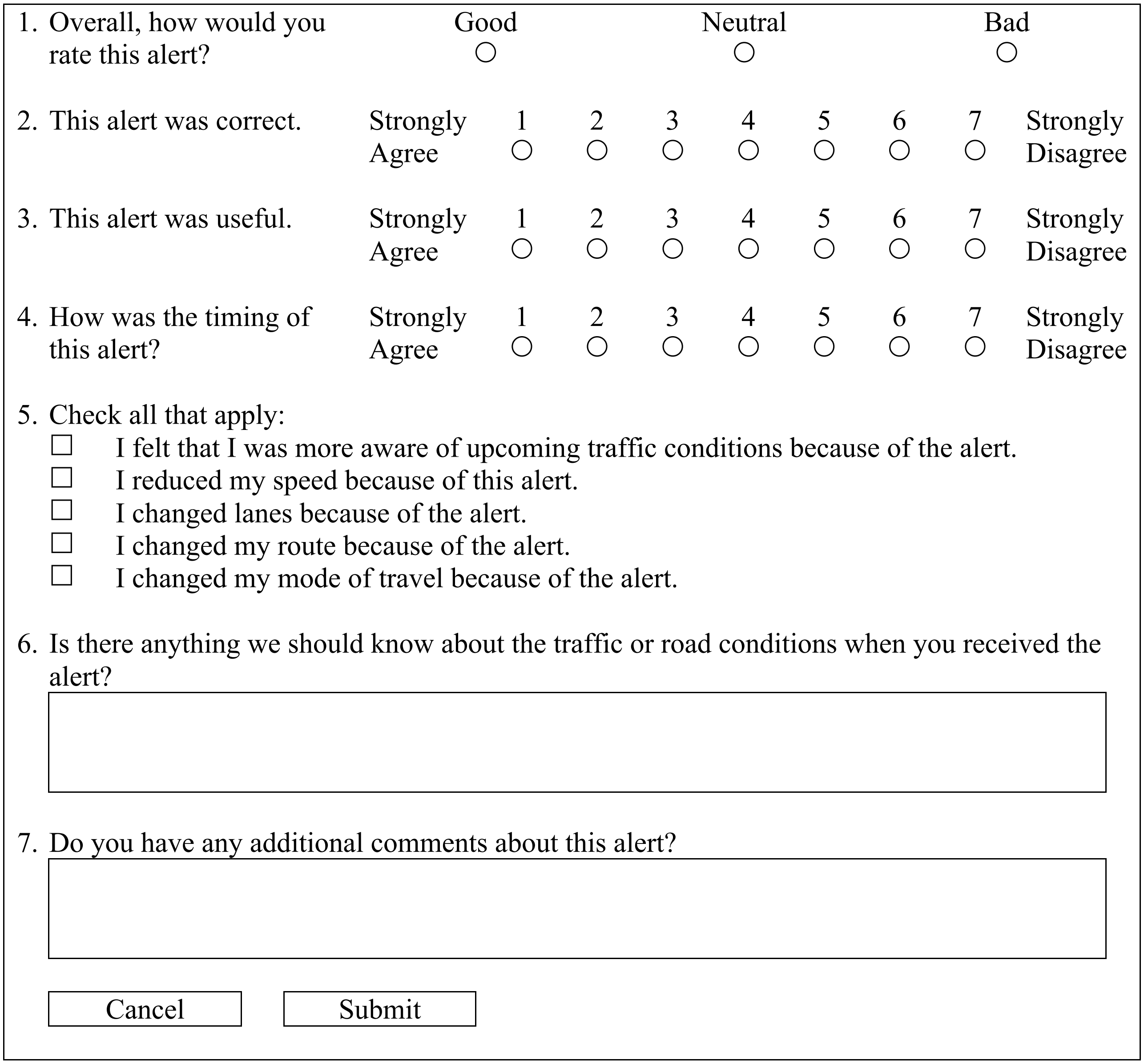
November 9, 2010

A. 11:12 AM. Rate this alert.

November 15, 2010
November 16, 2010
November 17, 2010

Figure 4.2: Participant Feedback Website.

When the participants logged into the feedback website with their user account and password, they were shown a list of dates when alerts were received during the study. Clicking on any particular date brought up a list of all the alerts received on that day (sorted by time received) along with a corresponding map displaying the location of each alert. Clicking on an alert in the map brought up information about the speed that the vehicle was traveling at the time of the alert and the speed of the traffic ahead. Clicking on the “Rate this alert” link for each alert brought up a web page with a short seven question survey that a participant could fill out about that particular alert. (See Figure 4.3.)



	Good	Neutral	Bad
1. Overall, how would you rate this alert?	○	○	○

		1	2	3	4	5	6	7	
2. This alert was correct.	Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree
3. This alert was useful.	Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree
4. How was the timing of this alert?	Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

5. Check all that apply:
   - ☐ I felt that I was more aware of upcoming traffic conditions because of the alert.
   - ☐ I reduced my speed because of this alert.
   - ☐ I changed lanes because of the alert.
   - ☐ I changed my route because of the alert.
   - ☐ I changed my mode of travel because of the alert.

6. Is there anything we should know about the traffic or road conditions when you received the alert?

7. Do you have any additional comments about this alert?

Figure 4.3: Per Alert Survey.

4.5.5 Participant Debriefing

The final part of the study was the vehicle return and participant exit interview. On the third Saturday morning of the experiment session, the participants returned the research vehicle to California PATH's Richmond Field Station. The participants were given one last opportunity to log into the study website and complete the on-line, per-alert surveys for any alerts that they had received but not yet rated. The participants were then given a half-hour exit interview. The exit interview was not conducted by California PATH or UC Berkeley researchers. It was conducted by researchers from SAIC International, a consulting firm contracted separately by the project sponsors to act as the project's independent evaluator. The result of from the exit interviews and the findings of the project's independent evaluation team are published separate from this report (Jasper, Golembiewski, Armstrong, and Miller, 2010).

After the exit interview, the participants met one last time with a California PATH experimenter to turn in the fuel card, any fuel receipts, and to receive a $100 cash incentive for participating in the experiment. The participants were then thanked and free to leave.

4.5.6 Vehicle Preparation, Maintenance, and Repairs

As the vehicles were returned by the participants exiting the study, there was a strict protocol that was followed to ready the vehicles for the next participant. (See Appendix E.) When the vehicles were returned they were cleaned, inspected, and the data for the previous participant was downloaded from the DAS. Furthermore, the vehicle's navigation system was cleared of any potentially identifying data left over from the previous participant, such as address book entries and recent destinations. Since there were only a few hours between experiment sessions, DAS malfunctions (usually related to camera failures) were not usually noticed until after the vehicle had been handed out to the next participant and the researchers had a chance to validate the data that had been downloaded from the DAS. Any DAS issues, along with general vehicle servicing and maintenance, were either repaired in the field or the participants graciously volunteered to schedule a time to return to the Richmond Field Station for repairs.

5 RESULTS

5.1 Data Set Overview

5.1.1 Vehicle Trips Recorded During the Experiment

Unlike a typical driving experiment, there was no set number of trials with the Networked Traveler Foresighted Driving ADAS. Instead, drivers were given free use of a test vehicle to drive as their own for a period of two weeks. There were 4 test vehicles used in this experiment, 2 were 2008 Nissan Altimas and 2 were 2007 Audi A3s. Because the different vehicles were introduced into the experiment as they became ready, 16 of the participants drove Nissan Altimas and 8 of the participants drove Audi A3s. Furthermore, since only one Audi A3 had a manual transmission, only 4 of the participants drove a vehicle with a manual transmission while 20 of the participants drove vehicles with automatic transmissions.

In understanding the data set, the first important concept is the concept of a trip. A trip was defined as being from the time the vehicle ignition is turned on until the time the vehicle ignition is turned off. From ignition on, the DAS generally starts recording data with a 1-2 minute delay for the systems to boot up, so it is possible that some trips are missing the first minute or so of driving. It was expected that there would be at least 20 commuting trips, 10 during the baseline week and 10 during the week where the ADAS was enabled, but as shown in Table 5.1, the number of trips recorded by each participant ranged from a low of 35 to a high of 131 with a mean of 75 (SD 25) trips per participant.

A total of 1808 trips were recorded during the study, but 1548 trips contained data that could be analyzed for this project. As shown in Table 5.2, as many as 35 trips per participant, 242 trips in total, contained no useful driving data. These consisted mostly of trips that were very short, and due to the delay in the DAS start-up, the only part of the trip that was recorded entailed the vehicle maneuvering into a parking space or simply idling. Additionally, a total of 18 trips contained good driving data, but these trips did not contain any Networked Traveler ADAS data. Two of those trips were the result of DAS failures, and the remainder 16 were generally the result of ADAS communications failures. These were due to a lack of cellular or internet communications. Either the vehicle was driving in an area that lacked adequate cellular communications coverage, or in several cases, the Networked Traveler web service experienced network outages. Finally, in a few of the cases, the failure was due to experimenter errors in configuring the vehicle for the participant.

In addition, there were a number of partial failures that resulted in a degraded quality of data. First, during 22 trips, mostly occurring with the Nissan Altima test vehicles during the first 4 participants, the DAS software that was collecting vehicle data from the vehicle CAN bus failed to start up properly. For these trips, the vehicle speed that was used to generate the alerts and is used in the subsequent analyses is based on the speed obtained from the GPS. During these trips, there is no way to determine when the driver activated the brake or turn signals. Second, on 57 trips, the MEMSense accelerometer and yaw rate sensor failed to start up properly. For these trips, yaw rate is unavailable and the vehicle acceleration is calculated based on the differentiation of the vehicle speed. Third, and finally, on some trips there were camera failures, either due to hardware failures or aiming issues; however, the video recordings were not integral to the data analysis.

In summary, the data set includes 1548 trips that contain both driving data and Networked Traveler ADAS data. A total of 766 trips were recorded during baseline testing weeks and 782 trips during the ADAS testing weeks. There is a mean of 31.9 (SD 10.0) baseline trips and 32.6 (SD 11.4) ADAS-enabled trips per participant. However, some participants have as few as 16 baseline or 18 ADAS-enabled trips, while others have as many as 55 baseline or 62 ADAS-enabled trips. The mean trip length is 24.9 (SD 22.4) minutes, with trips being recorded as short as 30 seconds and as long as 3 hours and 20 minutes. The mean number of Networked Traveler trigger points passed along each trip is 14.1 (SD 14.4), but some trips encountered no trigger points while others encountered as many as 79.

Table 5.1: Number of Trips Recorded by Participant.

Driver	Gender	Baseline Trips	ADAS Enabled Trips	Trips With No Driving Data	Trips With No NT Data	Total Number of Trips
1	Male	42	47	13	0	102
2	Female	42	37	22	0	101
3	Male	29	35	35	0	99
4	Male	31	22	14	0	67
5	Female	16	21	1	0	38
6	Male	55	62	12	2	131
7	Female	26	26	9	1	62
8	Female	28	18	10	2	58
9	Male	23	41	13	1	78
10	Male	27	25	9	1	62
11	Female	24	31	4	1	60
12	Male	38	33	8	5	84
13	Female	31	28	11	0	70
14	Female	47	43	14	3	107
15	Female	35	25	15	0	75
16	Female	44	37	18	0	99
17	Male	42	47	25	0	114
18	Female	35	35	1	0	71
19	Male	38	46	0	0	84
20	Female	21	30	5	1	57
21	Male	25	18	0	0	43
22	Male	29	38	2	0	69
23	Female	22	19	1	0	42
24	Male	16	18	0	1	35
Total	--	766	782	242	18	1808

5.1.2 Networked Traveler Alert Conditions Recorded During the Experiment

Based on the 1548 trips where usable data was recorded, during the first week of the experiment (the baseline week), there were 654 events over 275 trips where the Networked Traveler ADAS would have given an alert if the audio had not been muted. During the second week of the experiment (the alert week), there were 718 audible alerts issued to the drivers over 293 trips. As shown in the following table the number of alerts received by each driver varied widely.

Table 5.2: Networked Traveler Foresighted Driving ADAS Alerts per Participant.

Driver	Gender	Baseline Alerts (Muted)	Audible Alerts
1	Male	45	72
2	Female	27	27
3	Male	47	38
4	Male	53	42
5	Female	8	18
6	Male	27	30
7	Female	32	14
8	Female	37	25
9	Male	17	64
10	Male	41	35
11	Female	13	27
12	Male	13	23
13	Female	35	41
14	Female	27	27
15	Female	45	38
16	Female	25	37
17	Male	10	14
18	Female	18	15
19	Male	19	24
20	Female	18	14
21	Male	14	11
22	Male	19	27
23	Female	35	25
24	Male	29	30
Total	--	654	718

For the baseline alert conditions, the mean number of events per driver is 27.3 (SD 12.8). The minimum number of baseline alert conditions seen by a driver is 8, while the maximum is 53. For the audible alert conditions, the mean number of alerts per driver is 29.9 (SD 14.8). The minimum number of audible alerts seen by a driver is 11 and the maximum number is 72.

5.1.3 Alert Conditions Filtered for False Alarms

As described earlier in Section 3 of this report, there was concern over the high rate of false alarms with the system based on the comments made during the participant exit interviews, and a method was devised to try to automatically identify false alarms. However, as the analysis progressed, more false alarms were discovered and additional steps were taken to further identify and filter out false alarms. In the initial step, baseline and audible alerts were automatically labeled as false alarms if it took the driver more than 3 minutes to reach the targeted alert speed. This criteria eliminated about 40 percent of the baseline and audible alerts, resulting in a data set of 437 baseline events and 446 audible alerts.

In the second step, the list of audible alerts was manually filtered based the participant's subjective ratings and comments. An analyst scanned the participant's ratings and comments to find cases where the initial automated process had labeled an alert as good, but the participant had rated the alert poorly or otherwise had indicated that the alert was actually a false alarm. Likewise, the alerts that were labeled as false alarms in the initial processing step were scanned to find cases where the participant indicated that the alert was good. An analyst then verified each case by watching the video to determine whether or not the system functioned properly in that case.

Examining the cases where the automated process suggested that an alert was good, but the driver indicated that the alert was bad, an additional 40 audible alerts were found to be false alarms. In 27 of these 40 cases, an audible alert was given to the driver while he or she was on a freeway, but after the alert was given, the driver exited the freeway before encountering the slowed traffic. Although these cases might not have been false alarms from a system design standpoint, they were removed from the analysis because the deceleration profile executed by the driver was not based on the end-of-queue approach, but rather, it was based on freeway exiting maneuver. In the remaining 13 cases, the driver was simply not traveling on a freeway at the time that the alert occurred. These cases are not surprising given that the lack of map matching is a known limitation of the system that was built and tested.

There were also 37 cases found where the automated process suggested that an alert was bad, but the driver indicated that the alert was good. However, in each of these 37 cases, the video analysis clearly showed that the audible alert was a false alarm, and there was no traffic slow down encountered on the freeway. The subsequent vehicle deceleration (over three minutes later) was always related to a freeway exit maneuver.

Finally, since the underlying assumption of the protocol was that drivers would generally be driving the same routes during both the baseline and alert weeks, it would make sense that many of the audible false alarms should have counterparts experienced during the baseline week (where there was no driver feedback that could be used to identify the false alarms). Thus, in the third and final step of the false alarm identification process, a list of GPS locations where false audible alarms had been given was compiled. Then, all of the locations of baseline alert conditions were checked against the locations of known false alarms. A total of 46 baseline alert conditions were found to occur at locations associated with known audible false alarms. The video was then manually examined, and a total of 32 baseline alert events were also found to be false alarms.

As shown in Table 5.3, the filtering of false alarms greatly reduced the number of alerts that could be analyzed for each participant, and a total 405 baseline and 406 audible alerts are included in the final analysis. The mean number of baseline events per participant is 16.8 (SD 9.0), and the mean number of audible alerts per participant is 16.9 (SD 10.2). Additionally, using these filters, seven of the participants experienced less than the targeted two alert conditions per day, and one of the participants did not receive any valid alerts during the baseline week. Statistically, the analysis technique used does account for the variations in the number of repetitions by weighting. However, even if the 7 drivers with few alerts were discarded, there would remain 17 drivers who experienced the experiment's targeted two alerts per day, and the number of subjects run in the experiment remains greater than the minimum 14 drivers suggested by the *a priori* power calculations.

Table 5.3: ADAS Alerts per Participant with False Alerts Filtered Out.

Driver	Gender	Baseline Alerts (Muted)	Audible Alerts
1	Male	21	33
2	Female	20	21
3	Male	28	19
4	Male	25	25
5	Female	5	7
6	Male	19	11
7	Female	16	5
8	Female	29	13
9	Male	12	40
10	Male	26	27
11	Female	13	19
12	Male	6	6
13	Female	20	25
14	Female	13	15
15	Female	33	27
16	Female	21	32
17	Male	10	6
18	Female	14	10
19	Male	9	9
20	Female	11	11
21	Male	3	3
22	Male	0	6
23	Female	30	19
24	Male	21	17
Total	--	405	406

5.1.4 Alert Repetition

One of the known limitations of the Networked Traveler Foresighted Driving alerting system is the inherent possibility for driver to get multiple alerts for the same traffic slowdown. To try to compensate, the system only allowed for audible alerts to be played once every two minutes. However, this strategy failed in a number of different scenarios. First, since there were latencies in the traffic data, the end-of-queue may have moved downstream during the latency, causing the system to issue an alert early. Second, the traffic slowdown could occur in gradual phases. As an example, the first alert might be given to a vehicle traveling 65 mph when the speed ahead was only 15 mph. The second alert might be given several minutes later when the vehicle was travelling at 50 mph, and the speed ahead was only 35 mph. Finally, since the traffic speeds were not lane-specific, it was possible that the end-of-queue for the driver's lane was further downstream than was suggested by the mean traffic speed across all lanes. This tended to occur when drivers were using a carpool lane.

In the previous section on the filtering of false alarms, it is noted that cases where the vehicle did not reach the reported downstream sensor speed within three minutes were excluded from the data set that was analyzed in this report. However, since the system design allowed for the possibility of multiple alerts being given for the same traffic slowdown, the alerts that are included in the analysis are not necessarily the first alert that was received by the driver. As shown in Table 5.4, up to 25 percent of the alerts that are included in the analysis could have been repeats of alerts since they occurred within 4 minutes of a prior alert. Further analysis on the impact of these cases is not pursued in this report since it would have required the video for each individual case.

Table 5.4: Number of Cases by Alert Redundancy.

Alert Redundancy	Baseline Alerts (Muted)		Audible Alerts		Total Cases	
Novel Alert	311	76.8%	298	73.4%	609	75.1%
Possible Repeated Alert	94	23.2%	108	26.6%	202	24.9%
Totals	405	49.9%	406	50.1%	811	100.0%

5.1.5 Alert Condition Time of Day

Since the participants were given free use of the research vehicles, it was possible to encounter alerts during either the morning or evening commutes or during non-commuting travel. Thus, included in the subsequent analyses is an alert time-of-day factor. This factor contains three levels: morning commute, evening commute, and off-peak. The off-peak coding includes weekday alerts occurring between 10:30 AM and 3:00 PM and between 7:30 PM and 6:00 AM. The off-peak coding also includes all weekend alerts. The morning commute is defined as 6:00 AM to 10:30 PM, and evening commute is defined as 3:00 PM to 7:30 PM, Monday through Friday.

As shown in Table 5.5, there is a relatively balanced distribution of both baseline and audible alerts across the time-of-day coding. Roughly 40 percent of the alert conditions occurred during the morning and evening commutes, and 20 percent of the alert conditions occurred during off-peak hours or during the weekends.

Table 5.5: Number of Cases by Time of Day.

Time of Day	Baseline Alerts (Muted)		Audible Alerts		Total Cases	
Morning Commute	157	38.8%	162	39.9%	319	39.3%
Evening Commute	168	41.5%	167	41.1%	335	41.3%
Weekend/Off-Peak	80	19.8%	77	19.0%	157	19.4%
Totals	405	49.9%	406	50.1%	811	100.0%

5.2 Comparing Driver Performance Between the Baseline and Alert Weeks

5.2.1 Overview

5.2.1.1 Driver Performance Metrics Discussion

The ultimate goal of this study is to determine whether or not providing drivers with the Networked Traveler Foresighted Driving alerts would result in a reduction of rear-end, freeway end-of-queue crashes. However, even though there are an estimated 5.8M crashes each year, the crash rate is only about 1.98 per Million Vehicle Miles Traveled (MVMT) based on the traffic safety facts published by the National Highway Traffic Safety Administration (2008). Clearly, the scope of this study was too small to make any direct inferences on the benefits of a foresighted driving ADAS. Instead, the best that this study can hope to show is that there was a positive and measurable change in driver behavior between the baseline and alert conditions using surrogate metrics that are believed to be related to driving safety.

The literature review discussed earlier provided three surrogate safety metric inspirations on how the Networked Traveler Foresighted Driving alerting system might reduce end-of-queue, rear-end crashes. First, from the traffic engineering literature, minimizing the speed differentials of the vehicles in the traffic flow may reduce crashes. The methodology used in these studies generally employs an infrastructure sensor to record the speeds of all of the vehicles passing a particular point on the roadway. One then computes a standard deviation of speed across all drivers passing through the point. The literature shows reductions in this standard deviation are associated with reductions in accident rates (Zheng, Z., Ahn, S., Monsere, C.M. (2010)). However, the Networked Traveler subjects do not all pass through the same locations. Hence we compute a different but related measure of speed variability – the Root Mean Square (RMS) Error of Speed during the approach to the end-of-queue. This metric was only computed for a single vehicles during an end-of-queue approach. However, the metric is very similar to the standard deviation of speed, only it corrects for the heterogeneity of traffic conditions.

The second inspiration comes from more the more recent literature on naturalistic driving studies. Naturalistic driving studies have shown that rear-end collisions are typically associated with or the result of momentary driver inattention. Thus, one potential metric that could be examined in this study is the frequency of driver distraction while approaching the end-of-queue, and we would expect to see a decrease in distraction events in the audible alert condition. However, if we assume that driver distraction, at the moment of an end-of-queue encounter, is relatively rare, then this study would likely contain too few observations to accurately model this phenomena. Furthermore, this study was biased in terms of observing natural driver distractions since participants were explicitly warned about the dangers of driver distraction (in the consent form and in the driver orientation session), and they were prohibited from engaging in cell phone use (a common distraction) while driving in the study. Finally, the fact that they knew they were being filmed for a study may have encouraged them to be more attentive.

The final and most promising surrogate safety metric inspiration comes from the on-board driver monitoring literature. These studies have shown that even without understanding the causes of crashes, smoother driving, such as reduced lateral and longitudinal accelerations and decelerations, is associated with a lower crash risk. Thus, if the Networked Traveler Foresighted Driving ADAS can influence smoother speed changes, then it may lead to a reduction in crashes. Whether providing the Networked Traveler Foresighted Driving ADAS alerts reduces the probability of inopportune driver distraction or reduces misjudgments about the speed of traffic flow at the end-of-queue, a smoother deceleration profile into the end-of-queue should could indicative of a reduction in crash potential. Along these lines, five different driver performance metrics are examined, and each metric is an attempt to quantify how a smoother deceleration profile might appear.

1. Peak Deceleration Rate
2. Mean Deceleration Rate
3. Deceleration due to braking (vs. deceleration due to coasting)
4. Pre-Braking Deceleration
5. Standard Deviation of Speed / RMS Error of Speed

For each metric, the period of analysis begins at the point where the audible alert is issued to the driver (or where the audible alert would have occurred during the baseline events), and it continues until the vehicle reaches the targeted alert speed. Thus, if the vehicle was travelling at 70 mph when it received an alert advising the driver that the speed ahead was only 45 mph, then the period of analysis starts at the time of the audible alert and ends once the vehicle reaches a speed of 45 mph. The mean period of analysis in the data set is 66.3 (SD 40.9) seconds, and the maximum period of analysis is 3 minutes.

In 93 cases, the period of analysis is less than 20 seconds. In 62 of these cases, the first alert received by the driver for the traffic situation was simply late, and this was likely due to the fact that the location of the end-of-queue was not precisely known in some locations the infrastructure sensors were not closely spaced. In 31 of these cases, the driver received multiple alerts for the same traffic slowdown, and the first alert had been discarded as a false alarm because the vehicle took longer than 3 minutes to reach the targeted alert speed. The methodology for dealing with the variable length of the period of analysis varies by performance metric and is described in greater detail in the appropriate sections.

5.2.1.2 Experiment Design

The Networked Traveler Foresighted Driving field study employed a repeated measures design, where each participant saw both the control condition (the baseline week) and the treatment condition (the audible alert week). The analysis utilizes a repeated measures (mixed model), generalized linear model using the SPSS statistical software. The generalized linear model (SPSS's generalized estimating equation function) is an extension of the more typically found ANOVA analyses; however, this analysis technique does not have as many limitations as are typically found when using the ANOVA technique. Specifically, the generalized linear model can account for unequal sample sizes, missing cells, and non-normal distributions.

The general statistical model that is run for each driver performance metric includes gender as the primary between-subjects factor and alert condition (muted baseline vs. audible alert) as the primary within subjects factor. A second within-subjects factor that is included is the alert condition time of day (morning commute, evening commute, or off-peak). However, there is one additional factor that needs to be included in some of the models to compensate for any differences that may have inherently existed between each, individual baseline or alert trial condition.

As an example, the speed difference between the vehicle's initial speed at the time of the alert and the sensor speed ahead, will likely have some influence on the drivers deceleration rate. Additionally, the timing of the alert, whether the alert came 15 second or 2 minutes before the end-of-queue, could also have some influence on the driver's deceleration rate. Since these factors were not controlled in the study, the differences between trials due to these factors could easily overshadow any effects seen due to the absence or presence of an alert. Thus, where appropriate, a minimum required deceleration rate is included in the model as a covariate. For the purposes of the subsequent analyses, the minimum required deceleration rate is simply the straight-line deceleration rate required to reduce the vehicle's speed from the initial speed to the final traffic speed over the period of time that it took the driver to reach the final traffic speed.

All of the statistical models used in the subsequent analyses use an identity link function (assuming normality) unless otherwise stated. However, in some cases, alternative assumptions could be made. As an example, deceleration rates are modeled using an assumption of an underlying gamma distribution (with a logarithmic link function) to account for the fact that the minimum deceleration rate is fixed at just greater than zero and the distribution of deceleration rates generally has a long tail. This assumption is similar to the assumptions frequently made when analyzing metrics such as elapsed time or human reaction time. Finally, all models include only main effects and two-way interactions with the alert factor since adding higher order interactions has the potential to introduce sampling biases due to a lack of sufficient cases in each cell for each driver.

5.2.1 RMS Error of Speed

The final two driving performance metrics examined in this section are the standard deviation of the speed and a similar but alternate metric, the Root Mean Square (RMS) Error of the deceleration profile. The standard deviation of speed has been used in the literature in two cases. First, it is used in the traffic engineering literature as a measure of the variability of vehicle speeds in traffic flow, but that is not the same metric as the standard deviation of speed that is computed for a single vehicle while performing a speed change. Second, the standard deviation of speed is used in the human factors driving performance literature as a measure of dual task performance, typically when studying driver distraction. However, whenever the standard deviation of speed is used in the human factors literature, there is an assumption that the driver is traveling at a constant speed and is being asked to maintain that speed.

Generally speaking, the standard deviation is a metric that measures dispersion about the mean, and in the case of a deceleration profile, dispersion about the mean is meaningless. Take the two cases shown in figure 5.1 as examples. The first case shows a hard deceleration (0.4 g) from 65 to 30 mph, and the second case shows a smooth deceleration (0.05 g) for the same speed drop. Computing the standard deviation of the vehicle speed over the 30-second event results in 7.1 mph for the hard deceleration case, and it results in an increase to 10.1 mph for the smooth deceleration case. The standard is simply not a sensitive metric for measuring the smoothness of a deceleration profile over a change in velocity.

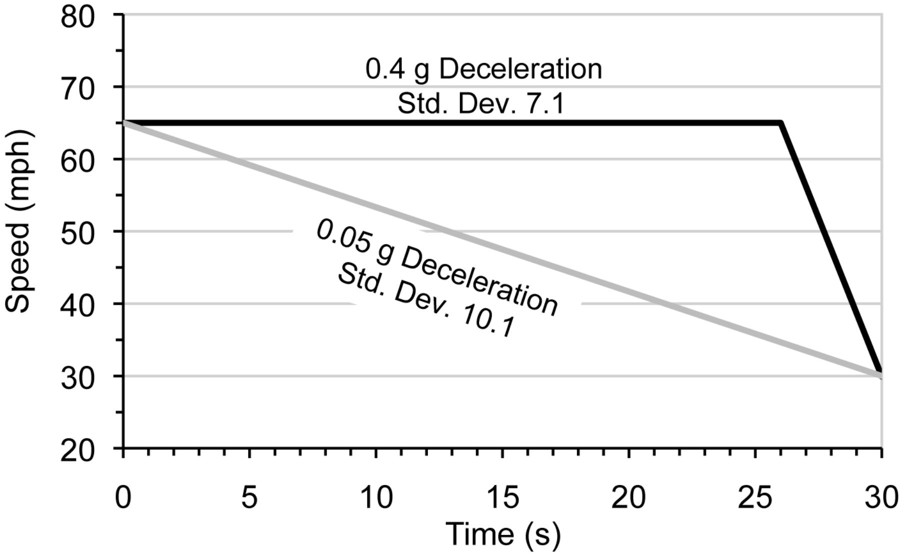


Figure 5.1: The Standard Deviation of Speed for Hard and Smooth Decelerations.

In the case where a vehicle speed change is anticipated, the smoothest possible deceleration profile is a straight-line deceleration over the entire allotted time period. When the problem is viewed in this light, an ideal metric for measuring the smoothness of a deceleration profile would incorporate the deviation of the observed deceleration profile from the ideal deceleration profile, and Root Mean Square (RMS) error is such a metric. RMS error is commonly used in much of the human performance literature involving tracking tasks.

For the current study, the ideal path used in RMS error is calculated based on a straight-line deceleration over the analysis period. (As a reminder, the analysis period was from the time the driver received the alert until the time that the vehicle reached the predicted downstream sensor speed.) The statistical model that is used for this analysis examines gender, alert, time of day, and all of the two-way interactions using an underlying assumption of a normal distribution (based on a visual inspection of the data). However, unlike previous analyses, the model does not include the covariate, minimum required deceleration, because the RMS Error calculation already accounts for this variation. The ideal deceleration profile used in the RMS error calculation is essentially the same minimum required deceleration that has been used as a covariate in the previous analyses.

The only significant effect in the model is the absence or presence of the Networked Traveler Foresighted Driving audible alert, Wald χ^2_1=6.292, p=.01. The mean RMS error for the baseline condition is 8.9 (SD 4.6) mph, and the presence of the audible alerts reduces the RMS error to a mean of 8.1 (SD 4.5) mph. A lower RMS error indicates that the deceleration profile was smoother, and thus, the data indicate that the deceleration profiles were smoother when the audible alert was present.

5.2.2 Peak Deceleration Rate

The peak deceleration rate is computed using the differentiation of vehicle speed, and it was verified for sanity using the instrumented vehicle's accelerometer when available. It should be noted that the peak deceleration rate, as computed for this metric, represents a momentary peak and does not represent a sustained deceleration rate. The peak deceleration rate is modeled using an assumption of an underlying gamma distribution (with a logarithmic link function), and the minimum required deceleration rate is used as a covariate in the model to account for the variability in the trial speed differences and the variability in the alert timing.

As expected, the primary significant factor influencing the drivers' peak deceleration rates is the covariate, the minimum required deceleration, Wald χ^2_1=92.877, p<.001. As shown in Figure 5.2, as the trial condition requires greater speed drops over shorter periods of time, there is a correlation between the minimum required deceleration rate and the peak observed deceleration rate. However, there are many cases where the minimum required deceleration rate was low, but the peak observed deceleration rate was high. These could represent situations where the driver was surprised by the traffic slowdown, or they could represent situations where the driver was simply reacting to a lead vehicle deceleration.

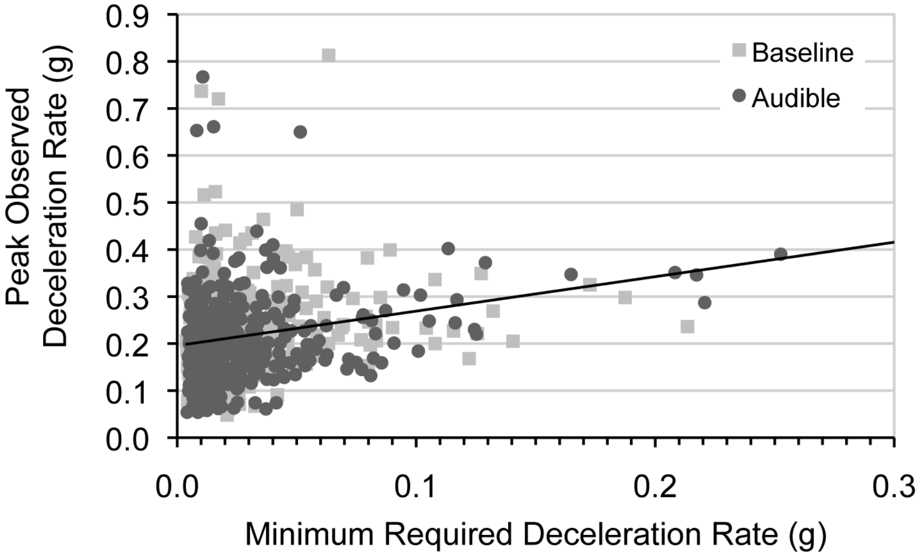
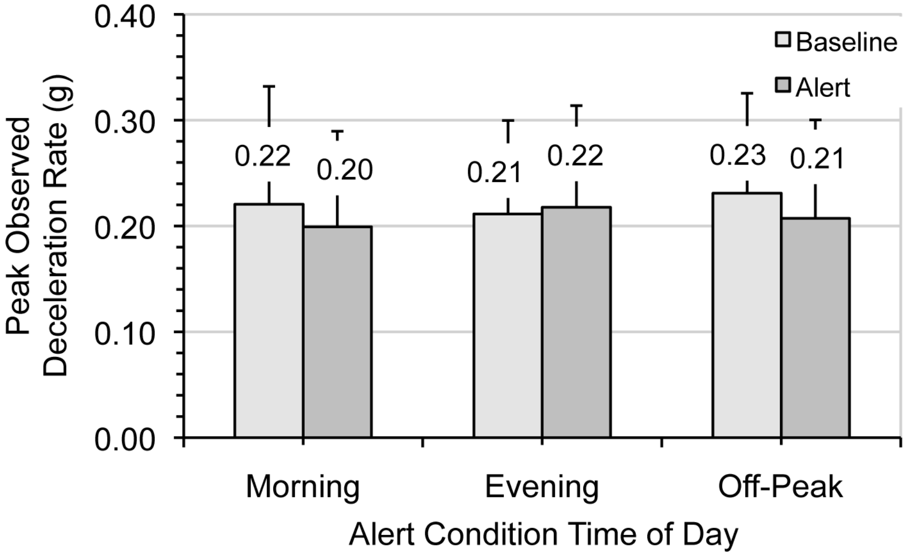


Figure 5.2: Peak Deceleration vs. Minimum Required Deceleration.

Although there is a reduction in the mean peak deceleration rate due to the presence of the Networked Traveler Foresighted Driving audible alert from 0.215 (SD .097) g in the baseline condition to 0.202 (SD .089) g in the audible alert condition, the effect is not statistically significant, Wald χ^2_1=2.270, p=.132. However, there is a significant interaction between the alert presence and the time of day, Wald χ^2_2=7.015, p=.03. As shown in Figure 5.3, the interaction between the presence of the audible alert and the time of day is both subtle and complex. Based on a pairwise comparison of estimated marginal means, the audible alert significantly reduced the mean peak deceleration rate only during the morning commutes and the off-peak hours. During the evening commutes, there is no significant difference between the baseline and the alert conditions.



(Note: Error Bars Denote 1 Standard Deviation)

Figure 5.3: The Effects of Alert and Time of Day on Peak Deceleration Rate.

5.2.3 Mean Deceleration Rate

Similar to the peak deceleration metric, the mean deceleration rate is based on deceleration derived from the differentiation of vehicle speed, and it was verified for sanity using the instrumented vehicle's accelerometer when available. The mean deceleration rate is computed as a time-weighted average of the vehicle's instantaneous deceleration rate, ignoring any time periods when the vehicle was not decelerating. Thus, the mean deceleration rate will exceed the minimum required deceleration rate if the vehicle spends any time coasting at a constant speed or accelerating before braking. A greater mean deceleration rate corresponds to a more abrupt speed profile over the entire course of slowing down to the queue, as opposed to the instantaneous measurement of the peak deceleration rate. The mean deceleration rate is modeled using an assumption of an underlying gamma distribution (with a logarithmic link function), and the minimum required deceleration rate is used as a covariate in the model to account for the variability in the trial speed differences and the variability in the alert timing.

Similar to the analysis of the peak deceleration rate, the mean deceleration rate is significantly correlated with the covariate, minimum required deceleration rate, Wald χ^2_1=573.238, p<.001. As shown in Figure 5.4 the mean observed deceleration was well correlated with the minimum required deceleration rate. The main effect of the audible alert is again not significant, but there are significant interactions between the alert presence and both the time of day and the minimum required deceleration covariate, Wald χ^2_2=7.021, p=.03 and Wald χ^2_1=8.961, p=.003, respectively. These interactions are described in more detail in Figures 5.4 and 5.5.

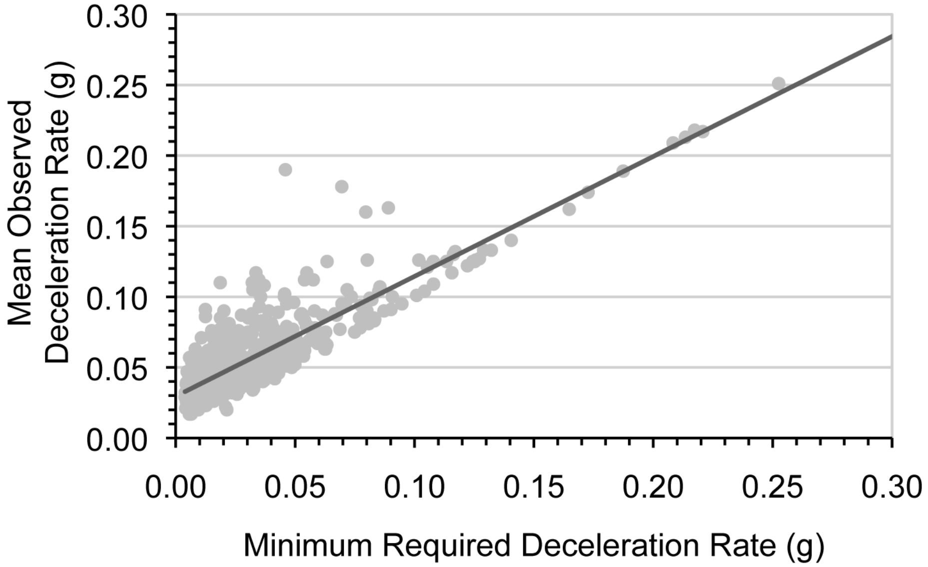


Figure 5.4: Mean Observed Deceleration Rate vs. Minimum Required Deceleration Rate.

The significant interaction between the alert presence and the time of day is shown in Figure 5.5. Based on the statistical significance of pairwise comparison tests of the marginal means, the alert is only effective at reducing the mean observed deceleration rate during the morning commute and during off-peak hours. The difference between the baseline and alert conditions during the evening commute is not statistically significant.

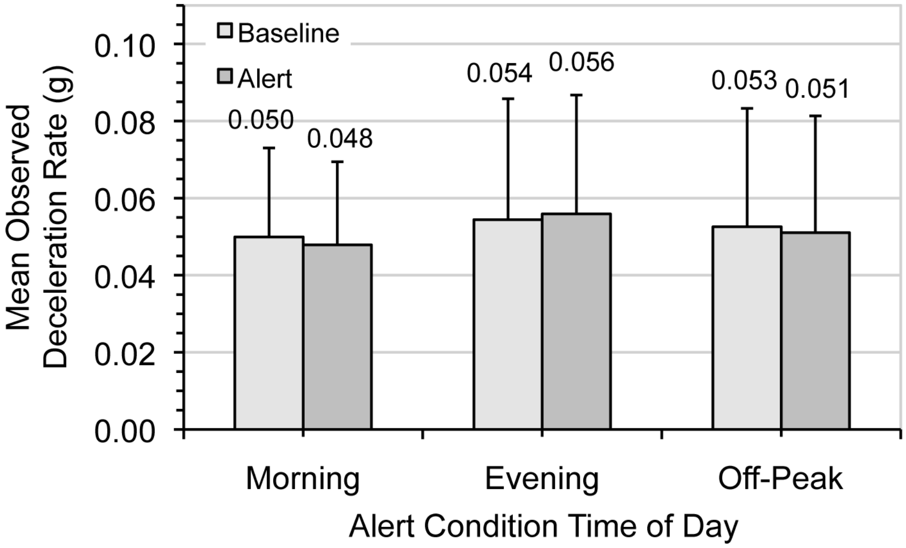


Figure 5.5: The Effects of Alert and Time of Day on the Mean Deceleration Rate.

The significant interaction between the alert presence and the minimum required deceleration for the mean observable deceleration rate is shown in Figure 5.6. The effect of the interaction is subtle, but it can be seen by comparing the projected slopes of the regression trend lines for the baseline and alert conditions. As the minimum required deceleration rate increases (more deceleration was required in a shorter amount of time), the audible alerts become more effective at reducing the mean deceleration rates as compared to the baseline condition. However, both the nature and the usefulness of this interaction are suspect. Had the Networked Traveler ADAS alert system been working as designed, there would never have been a minimum required deceleration rate exceeding 0.1 g, which is where the interaction shows the alert to start becoming more effective.

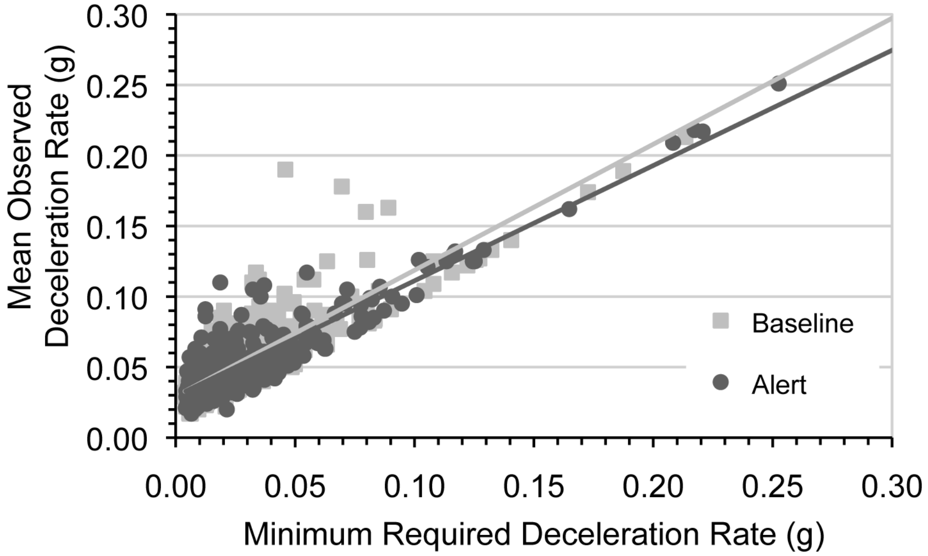


Figure 5.6: The Interaction Between the Alert Condition and the Minimum Required Deceleration Rate.

5.2.4 Deceleration From Braking

In the on-board driver monitoring systems literature, there have been a number attempts to link fuel efficient or “green” driving with safe driving (Young, Birrell, and Stanton, 2011), and the two driving performance metrics that are examined in this section are inspired by the eco-driving literature: (1) the percent of deceleration due to active braking and (2) the amount of deceleration due to coasting before the start of active braking. The first metric, percent of deceleration due to active braking, is calculated as the percent of the speed reduction between the initial vehicle speed and the final vehicle speed that is directly attributed to active braking by the driver. The concept behind this metric is that if the deceleration is more gradual, then a larger percentage of the speed change would be due to deceleration while coasting, instead of being due to deceleration while actively braking. Thus, a lower percentage of speed reduction due to braking would indicated a smoother deceleration profile. The analysis of this metric uses the same statistical model as was used in the analysis of the previous metrics, again, assuming an underlying gamma distribution. However, it should be noted that 72 of the 811 baseline and audible alert cases were excluded from this analysis because of a lack of brake activation information (generally due to failures of the data collection system's interface to the vehicle's CAN data bus).

Unlike the analyses of the braking rates, none of the model factors are significant for the percent of deceleration due to braking. Overall, a mean of 80.7 percent (SD 43.9 percentage points) of the deceleration is due to active driver braking, and there are no differences between the baseline and the audible alert conditions. In some cases there was almost no deceleration due to active braking, but in other cases the vehicle decelerated, reaccelerated, and then decelerated several times before reaching the target alert speed.

The second metric, the percent of deceleration before the start of braking, attempts to capture whether or not drivers began their deceleration by coasting earlier because of the audible alert. Given that the alert provided 60 seconds or more of preview about the traffic conditions, drivers were not expected to begin actively braking immediately following the alert, but it would be conceivable that some drivers might be more prone to reduce their speed by letting off the accelerator after hearing the alert. If this is the case, then we should see an increased amount of deceleration before the activation of the brake.

Unfortunately, modeling the percent of deceleration before the start of braking is not straightforward. The data does not follow either the normal distribution or the gamma distribution because in nearly one-third of the cases, the drivers did not decelerate before the start of active braking. The assumption of normality is violated because there can be no values lower than 0 percent, and the assumption of a gamma distribution would disregard all of the zero cases (where the driver did not decelerate before braking). Fortunately, this problem is similar to one faced by the insurance industry when modeling losses across policies. As described in Meyers (2009), the Tweedie distribution can be used to account for this type of data since it is the combination of a Poisson distribution to model the discrete portion and the gamma distribution to model continuous portion of the data. Thus, the percent of deceleration before the start of braking was modeled using a Tweedie distribution with a log link function.

The only model parameter that was significant in the analysis was the covariate, the minimum required deceleration, Wald χ^2_1=20.969, p<.001. This was not surprising and simply indicated that as the minimum required deceleration increased, the amount of coasting before braking decreased. As shown in Table 5.6, in 33 percent of the cases, there is no deceleration prior to braking, and this percentage remains constant across the baseline and audible alert conditions. For the cases where the driver did decelerate prior to braking, there is no difference between the baseline and audible alert conditions. Overall, a mean of 28.1 percent (SD 23.5 percentage points) of the deceleration is due to coasting, but the median is only 21.9 percent because the mean is skewed by a few cases where most of the deceleration was due to coasting.

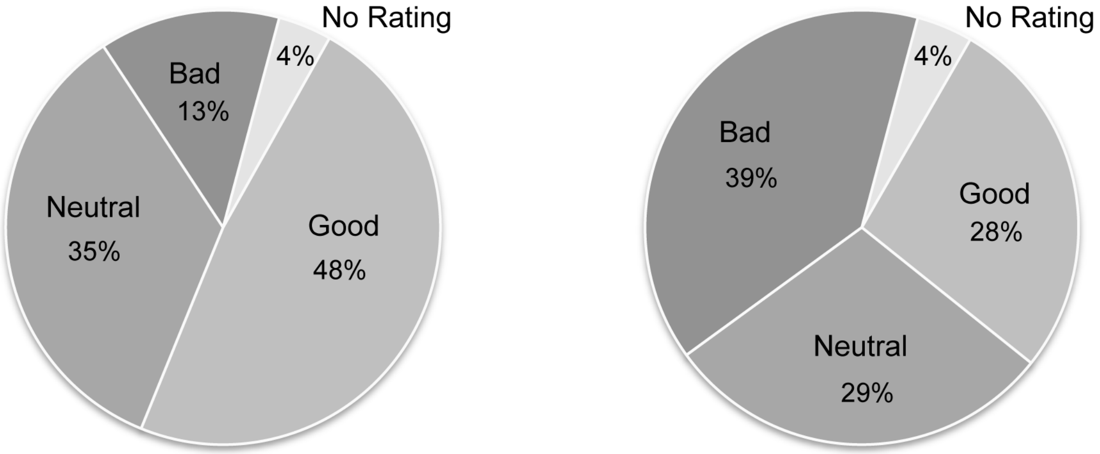
Table 5.6: Number of Cases of Deceleration Before Braking by Condition.

Prior to Braking	Baseline		Audible		Total	
No Deceleration	124	33.9%	120	32.2%	244	33.0%
Some Deceleration	242	66.1%	253	67.8%	495	67.0%
Total	366	49.5%	373	50.5%	739	100.0%

5.3 Analysis of Driver Survey Data

5.3.1 Overview

Out of the 718 audible alerts recorded during the study (including the alerts that were later determined to be false alarms), the participants filled out on-line surveys for 590 of the alerts and provided free form comments on 325 of the alerts. As described earlier in Section 5.1.3, 406 audible alerts were categorized as correct alerts, and they were included in most of the previously described analyses. The other 312 were determined to likely be system false alarms, partly based on the driver rating and comments which will be described in more detail in this section. The overall driver ratings for both the correct and false alerts are shown in Figure 5.7.



Correct Alert Ratings

False Alarm Ratings

Figure 5.7: Driver Ratings for Correct and False Alerts.

For the audible alert events that were categorized as correct alerts and rated by the drivers, 48 percent of the alert were rated as good by the drivers, 35 percent as neutral, and only 13 percent were rated as bad. Conversely, for the audible alert events that were categorized as false alerts and rated by the drivers, only 28 percent were rated as good, 29 percent as neutral, and 39 percent were rated as bad. While there was some correlation between the overall driver ratings and whether or not the alert worked as intended, it was not a very strong correlation.

5.3.2 Driver Ratings and Comments During False Alarm Events

There was a multistage process for detecting and verifying suspected system false alarms. First, alert events were automatically screened to determine how long it took the vehicle's speed to drop from the initial speed at the time of the alert to the speed indicated by the downstream sensors. If it took the vehicle longer than 3 minutes to reach the downstream sensors speed, the events were labeled as system false alarms. This labeled 272 audible alert events as false alarms, and 226 of those false alarms contained driver ratings and comments. In the second stage, the comments for all of the audible alert events labeled as correct alerts were scanned, and 37 events were found to have comments indicating that the event was likely a false alarm. (These events were manually verified using the video to determine that they were, in fact, system false alarms.)

Thus, a total of 263 audible alert events contained driver ratings or comments and were labeled as false alarms. While the driver ratings of these false alarms did not appear to provide much insight as what happened, 148 of the audible alert events contained driver comments. Based on these comments and some limited video analysis of events, the three most common reasons for system false alarms were as follows:

1. No traffic queue encountered probably due to incorrect or delayed traffic data (70.3 percent)
2. The driver took an exit before encountering the traffic queue (22.3 percent)
3. The driver was not on a freeway when the alert was received (7.4 percent)

The individual alert ratings were not examined in more detail because there appeared to be a large disconnect between the drivers' overall ratings of the alerts and the comments indicating that the alert was a false alarm. In 56.7 percent of the cases where the drivers clearly commented that an alert was a false alarm, the overall rating was either good or neutral for that same alert. Similarly, in 37 of the 226 cases where audible alerts were categorized as false alarms (because it took the vehicle more than 3 minutes to reach the targeted alert speed), the drivers' comments were subjectively positive towards the alert.

The positive comments on false alarms typically indicated that the queue was expected but the alert was good, the alert was a little late or for the wrong speed, or that the alert was otherwise considered good. In each of these cases, an analyst watched the video of the event, and in all 37 cases, the drivers encountered no traffic queue before exiting the freeway. Quite possibly, this disconnect could have been due to the delay between experiencing the alert and logging onto the website to rate the alerts. Since the drivers were unable to provide instant feedback, the drivers may have confused alerts or simply remembered the situation incorrectly.

5.3.3 Driver Ratings and Comments During Correct Alert Events

Out of the 406 audible alerts that were considered correct alerts and included in the analysis, the drivers provided ratings and comments for 327 of events. In addition to the overall alert rating, each alert was rated on a scale of 1 to 7 for correctness, usefulness, and timing. For correctness and usefulness, a rating of 1 was good and 7 was bad, and for timing, a rating of 4 was good, 1 was too early, and 7 was too late. The mean rating for the correctness was 3.1 (SD 2.0), and the mean rating for usefulness was 3.4 (SD 1.5), indicating that overall, the opinion of the alerts was slightly better than neutral. Figure 5.8 shows the percentage of alerts with each rating. For correctness, 77 percent of the alerts were rated as neutral or positive, and for usefulness, 75 percent of the alerts were rated as neutral or positive. For the timing, 41 percent of the alerts were rated as having OK timing, but 48 percent were rated as early and 11 percent were rated as late.

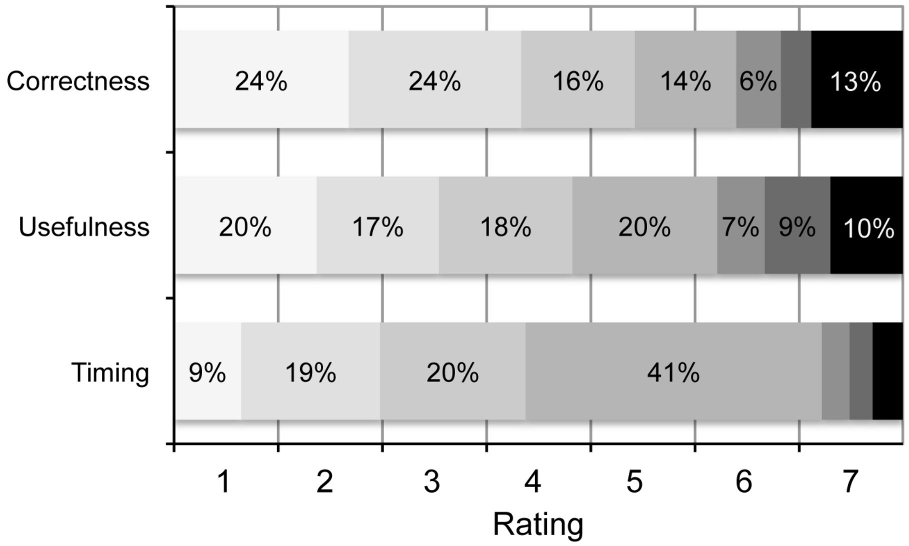


Figure 5.8: Percentage of Rated Alerts by Rating.

All of the comments made by the drivers were scanned and categorized by an analyst. As shown in Figure 5.9, the comments fell in to 8 general categories. In the first two categories, the alerts were typically rated as good or neutral, and the comments indicated that the alerts were well received. The general praise category contained comments such as “good alert”, “correct alert”, “good timing”, and a description of the traffic situation. In the early alert category, the comments indicated that the alert was good, but came too early. For these cases, the mean time for the vehicle to reach the alert speed was 90 (SD 30) seconds, and the longest time to reach the alert speed was just over 2 minutes.

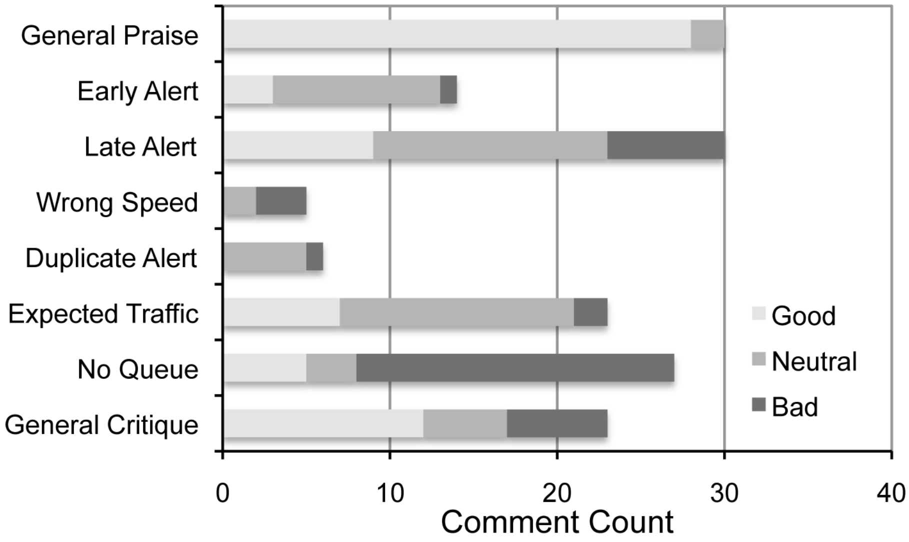


Figure 5.9: Summary of Comment Categories and Ratings.

The remain six comment categories contained subjectively negative comments about the alert or the system; however, in many cases the overall ratings were not necessarily weighted towards bad. For the late alert category, most of the comments indicated that the drivers could already see traffic slowing down ahead. Based on these cases, the mean time for the vehicle to reach the alert speed was 50 (SD 40) seconds, although the times ranged from about 5 seconds to 2.5 minutes. The comments suggesting that the alert gave an incorrect speed were split between the alert speed being too low or too high, and for the cases where the drivers indicated that an alert was a duplicated, the last alert given occurred anywhere between 2 and 4 minutes prior.

The comments that fell into the expected traffic category generally suggested that the location usually experienced slow traffic, such as freeway merges or toll plazas. The comments indicating that there was no queue or traffic slowdown were of concern as potential false alarms, and the video for all of these cases were examined by an analyst. However, in all of these cases, the analyst found that the alert was correct, and there was a traffic slowdown. In these cases, the driver may have confused the alert that they were rating.

The final category of comments included general system or situational critiques. In some cases, the system muted the stereo, but did not actually play the audible alert. In other cases, the alert occurred when the vehicle was on a ramp, and the driver was not sure whether the alert applied to the freeway that the driver was exiting or the freeway that the driver was entering. Otherwise, the comments in this category were simply of the nature of “bad alert” or “not useful.” Although it appears that more open-ended comments were given of a negative nature, this is not unexpected or uncommon. There is often a negative feedback bias when soliciting survey responses.

6 CONCLUSIONS

The purpose of the Networked Traveler Foresighted Driving field experiment was to test the effectiveness of an Advanced Driver Assistance System (ADAS) capable of providing drivers with soft-safety alerts regarding “Slow Traffic Ahead” when driving on a freeway. The experiment hypothesis is that providing drivers with these kinds of alert will result in smoother deceleration profiles as they approach dangerous end-of-queue traffic scenarios. The experiment, conducted on public roads using 24 drivers recruited from the San Francisco Bay Area, shows significant positive results for the alert on a number of driving performance metrics geared towards trying to measure deceleration profile smoothness. Overall, driver feedback on the system was also relatively positive. When the system worked as intended, 83 percent of the alerts received by the drivers were rated as either good or neutral, and only 13 percent were rated as bad. When alerts were rated as bad, the typical reasons included wrong speed, late alert, or some indication that the traffic conditions were either expected or otherwise not worth reported to the driver.

The literature provides three ideas on how the Networked Traveler Foresighted Driving alerting system might reduce end-of-queue, rear-end crashes. First, from the traffic engineering literature, minimizing the speed differentials of the vehicles in the traffic flow may reduce crashes. Second, from naturalistic driving studies, increasing the driver’s expectation of a speed change may reduce the chance that the driver will be distracted when encountering the end-of-queue scenario which may result in a reduction in crashes. Third, and finally, from the On-Board Monitoring System literature, there is a notion that smoother driving is associated with lower crash risk, and thus, if the alerting system can influence smoother speed changes, then it may lead to a reduction in crashes. This report mainly focuses on the this third idea using quantifying metrics such as the Root Mean Square (RMS) Error of Speed, Peak Deceleration Rate, Mean Deceleration Rate, Deceleration Due to Braking, Pre-Braking Deceleration, and Time before the start of braking. The first three of these metrics show support for the test hypothesis while the last two metrics did not appear to be affected by any of the factors tested in this study.

The experiment that was conducted utilizes a repeated measures design with each subject driving one of test vehicles without alerts for one week and with alerts for the second week. Of the metrics tested, the RMS Error of Speed best confirms the test hypothesis, showing that the presence of a “slow traffic ahead” alert results in a lower RMS Error. The metric captures the variability of speed as a driver approaches an end-of-queue. Participants exhibit a smoother approach to traffic queues in the alert week than in the non-alert week. Thus, enhanced situational awareness results in a smoother driving speed profile during the end-of-queue approach. This is heartening because, this measure is closely related to the measure found statistically significant in an earlier evaluation of this concept, but on a smartPhone platform, with an independently chosen pool of 14 subjects (Manasseh, C., Fallah, Y., Sengupta, R., and Misener, J. (2010)). This measure is also most closely related to the standard deviation of speed used in the traffic calming literature, which shows that each 1 mph increase in the standard deviation of speed measured at a detector results in an 8.4 percent increase in the crash risk (Zheng, Ahn, and Monsere, 2010).

Of the remaining metrics tested, both the peak and mean deceleration rates also support the test hypothesis, but they support it more weakly. There is a statistically significant reduction in both the peak and mean deceleration rates when the audible "slow traffic ahead" alert was present, but the reduction in the deceleration rates did not hold for all times of day. During morning commutes and off-peak travel, the audible alert reduced the drivers deceleration rates, but during the evening commutes, there is no difference between the baseline and alert conditions. It is well known that evening commuting hours are more congested, and the lack of an alert effect can perhaps be explained by the fact that recurrent congestion during the evening commuting hours is simply more predictable. This hypothesis was suggested by several of the drivers during the exit interviews.

Furthermore, although the reductions in the mean peak deceleration rate and the mean mean deceleration rate are statistically significant between some baseline and alert conditions, the magnitude of the reductions in the means is only on the order of .01 or .02 g. While on the surface, these reductions may not seem practically significant, the repeated measures generalized linear model analysis method may not capture the whole story because the technique is centered around testing for changes in distribution means. However, the best outcome of enhanced situational awareness may not necessarily be seen in a reduction in the mean of the distribution of peak or mean deceleration rates, but a reduction in the extreme values or the hard decelerations. Unfortunately, in this study, there were very few events (on the order of 6) with peak deceleration rates that exceeded 0.5 g (a value typically associated with hard braking), so it was impossible to examine the data using more advanced techniques, such as Extreme Value Theory. Based on the data collected in this study, an analysis of the tails of the braking distribution would require a much larger and much longer study to be able to capture drivers being surprised by the end-of-queue. As was noted by many of the drivers, they already knew where to expect end-of-queues on their daily commutes.

In summary, the Networked Traveler Foresighted Driving field experiment tested a prototype end-of-queue alerting system on freeways in the San Francisco Bay Area. The drivers who participated in the study expressed positive opinions about the system, and an analysis of the resulting driving data showed that the presence of the audible alert system enhances driver situational awareness and influences the smoothness of the drivers' end-of-queue approaches along several metrics.

As a final note, a listing of the peer reviewed publications related to this project to date as of the time of this report has been included in Appendix F.

ACKNOWLEDGEMENTS

The project is grateful to its partners the Metropolitan Transportation Commision, Navteq, and SpeedInfo for freeway traffic data, to the Nissan and Audi corporations for the test cars, and to Caltrans for access to right-of-way.

REFERENCES

Brovold, S., Ward, N., Donath, M., Simon, S., Shankwitz, C., Creaser, J. (2007). The use of technology to address patterns of risk among teenage drivers. *Journal of Safety Research*, 38, pp. 413-422.

Cirillo, J.A. (1968). Interstate System Accident Research - Study II - Interim Report II. *Public Roads*, Vol. 35, No. 3.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Cody, D. (2005). Application of Situational Awareness to Driving: Design of Lane Change Assistant. *Proceedings of the 12th World Congress for Intelligent Transport Systems and Services.* San Francisco, California, November 6-10.

Chan, C.Y., Manasseh, C., and Rezaei, S. (2010). Experimental Design and Evaluation of Networked Traveler Field Tests of Safety Applications in California. *Proceedings of the 2010 IEEE Intelligent Vehicles Symposium*. San Diego, CA, June 21-24. Los Alamitos, CA: IEEE.

Dingus, T., Klauer, S., Neale, V., Petersen, A., Lee, S., Sudweeks, J., Perez, M., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z., Jermeland, J., and Knipling, R. (2006). *The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car Field Experiment* (DOT HS 810 593). Washington, D.C.: National Highway Traffic Safety Administration, US Department of Transportation.

Faul, F., Erdfelder, E., Lang, A.G., and Buchner, A. (2007). G*Power3: A flexible statistical power analysis program for social, behavioral, and biomedical sciences. *Behavior Research Methods 39*(2), 175-191.

Fildes, B.N., G. Rumbold, and A. Leening. (1991). *Speed Behavior and Drivers' Attitude to Speeding* (Report 16). Monash University Accident Research Center, Monash, Victoria, Australia, June.

Hickman, J. and Hanowski, R. (2011). Use of a video monitoring approach to reduce at-risk driving behaviors in commercial vehicle operations. *Transportation Research: Part F*, 14, pp. 189-198.

Jasper, K., Golembiewski, G., Armstrong, C., and Miller, S. (2010). *National Evaluation of the SafeTrip-21 Initiative: Final Report: Networked Traveler-Foresighted Driving* (Technical Report Contract Number: DTFH61-06-D-00005 Task Order T-09-008). Mclean, VA: Science Applications International Corporation (SAIC).

Klauer, S., Dingus, T., Neale, V., Sudweeks, J., Ramsey, D. (2006). *The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data* (DOT HS 810 594). Washington, D.C.: National Highway Traffic Safety Administration, US Department of Transportation.

Klauer, S., Guo, F., Sudweeks, J., and Dingus, T. (2010). *An Analysis of Driver Inattention Using a Case-Crossover Approach 100-Car Data: Final Report* (DOT HS 811 334). Washington, D.C.: National Highway Traffic Safety Administration, US Department of Transportation.

Lotan, T. and Toledo, T. (2006). An In-Vehicle Data Recorder for Evaluation of Driving Behavior and Safety. Proceedings of the 85th Annual Transportation Research Board Meeting. Washington, D.C.: January 22-26.

Manasseh, C., Fallah, Y., Sengupta, R., and Misener, J. (2010). Using Smartphones to Enable Situation Awareness on Highways. *Proceedings of ITS America's 20th Annual Meeting and Exposition*. Houston, TX, May 3-5. Washington, D.C.: Intelligent Transportation Society of America.

Meyers, G. (2009). Pure Premium Regression with the Tweedie Model. *The Actuarial Review* (May Newsletter). Arlington, VA: Casualty Actuarial Society. [Online: http://www.casact.org/newsletter/pdfUpload/ar/Brainstorms_corrected_from_AR_May2009.pdf]

Miller, S., Rephlo, J., Armstrong, C., Jasper, K., and Golembiewski, G. (2011). *National Evaluation of the SafeTrip-21 Initiative: Combined Final Report* (Technical Report Contract Number: DTFH61-06-D-00005 Task Order T-09-008). Mclean, VA: Science Applications International Corporation (SAIC).

Misener, J., Sengupta, R., Ahern, K., Datta Gupta, S., Dickey, S., Kuhn, T., Lian, T., Manasseh, C., Nelson, D., Rezai, S., Sarafsaleh, A., Shladover, S., and VanderWerf, J. (2010). *VII California: Development and Deployment Proof of Concept and Group-Enabled Mobility and Safety (GEMS)*, (Technical Report UCB-ITS-PRR-2010-26). Berkeley, CA: California PATH, Institute of Transportation Studies, University of California, Berkeley.

Misener, J., Nowakowski, C., Lu, X., Koo, T., Margulici, J.D., Spring, J., Johnston, S., Kim, Z., Dickey, S., Kuhn, K., Kretz, P., Robin, J., and Walker, M. (2007). *Onboard Monitoring and Reporting for Commercial Motor Vehicle Safety Final Report* (Technical Report FMCSA-RRT-07-030). Washington, D.C.: Office of Research and Analysis, Federal Motor Carrier Safety Administration, U.S. Department of Transportation.

Musicant, O., Lotan, T., and Toledo, T. (2007). Safety correlation and implications of an in-vehicle data recorder on driver behavior. Proceedings of the 86th Annual Transportation Research Board Meeting. Washington, D.C.: January 21-25.

National Highway Traffic Safety Administration. (2008). *Traffic Safety Facts 2008 Data* (Technical Report DOT HS 811 160). Washington, D.C.: NHTSA, U.S. Department of Transportation.

National Highway Traffic Safety Administration. (2008). *Integrated Vehicle-Based Safety Systems (IVBSS) Phase I Interim Report* (Technical Report DOT-HS-810-952). Washington, D.C.: NHTSA, U.S. Department of Transportation.

National Highway Traffic Safety Administration. (2005). *Automotive Collision Avoidance System Field Operational Test Final Program Report* (Cooperative Agreement No. DTNH22-99-H-07019 Deliverable 42). Washington, D.C.: NHTSA, U.S. Department of Transportation.

National Highway Traffic Safety Administration. (1992). *NHTSA IVHS Plan* (Technical Report DOT-HS-807-850). Washington DC: NHTSA, Office of Crash Avoidance Research, U.S. Department of Transportation.

Pande, A. and Abdel-Aty, M. (2006). Comprehensive Analysis of the Relationship Between Real-Time Traffic Surveillance Data and Rear-End Crashes on Freeways. *Transportation Research Record: Journal of the Transportation Research Board, No. 1953*. Washington, D.C.: Transportation Research Board of the National Academies.

Pham, M.-H., Bhaskar, A., Chung, E., and Dumont, A.-G. (2010). Random Forest Models for Identifying Motorway Rear-End Crash Risks Using Disaggregate Data. *13th International IEEE Annual Conference on Intelligent Transportation Systems.* Madeira Island, Portugal: September 19-22.

Solomon, D. (1964). *Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle.* Bureau of Public Roads, U.S. Department of Commerce, July, 44 pp.

Stuster, J., and Z. Coffman. (1997). *Synthesis of Safety Research Related to Speed and Speed Management* (unpublished draft). Anacapa Sciences, Inc. Santa Barbara, Calif., FHWA, U.S. Department of Transportation, 56 pp.

Transportation Research Board. (1998). *Managing Speed: Review of the Current Practice for Setting and Enforcing Speed Limits (Special Report 254).* Washington, D.C.: National Academy Press.

West, L.B., Jr., and J.W. Dunn. (1971). Accidents, Speed Deviation and Speed Limits. *Traffic Engineering*, Vol. 41, No. 10, pp. 52–55.

Work, D., Bayen, A., and Jacobson, Q. (2008). Automotive Cyber Physical Systems in the Context of Human Mobility. *National Workshop on High-Confidence Automotive Cyber-Physical Systems.* Troy, MI: April 3-4.

Young, M., Birrell, S., and Stanton, N. (2011). Safe driving in a green world: A review of driver performance benchmarks and technologies to support ‘smart’ driving. *Applied Ergonomics*, 42, pp. 533-539.

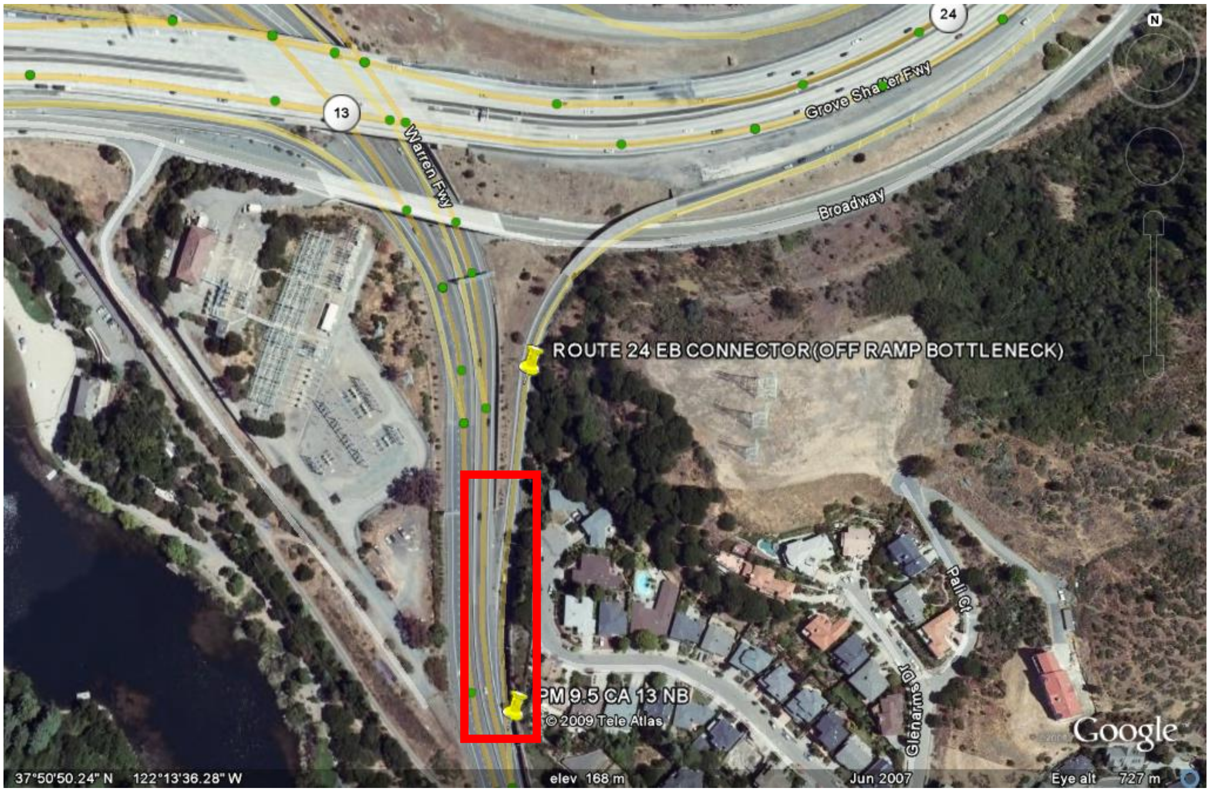
Zheng, Z., Ahn, S., Monsere, C.M. (2010). Impact of traffic oscillations on freeway crash occurrences. *Accident Analysis and Prevention*, 42(2), pp. 626-636.

APPENDIX A – DETAILED END-OF-QUEUE SITE ANALYSIS

1) Ala-13 PM R9.5, in northbound direction approaching Route 24 connector in Oakland. This location experienced traffic back-up from the connector to eastbound Route 24. **(Off-ramp bottleneck)**

Point of traffic detection: (Marked by a red box)

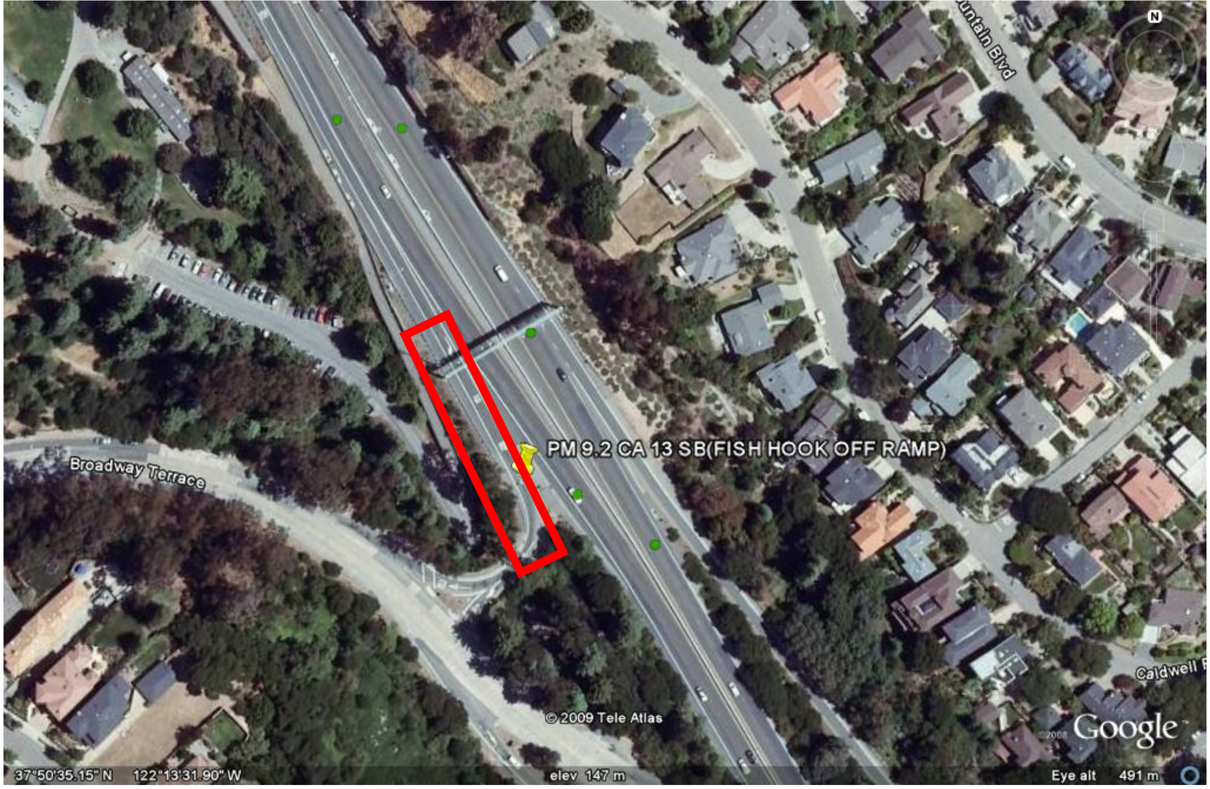
- Just slightly north of the pin marker at the bottom of the picture around the curve, before the off ramp begins.
- Primarily interested in the potential queue on the right lane, but both lanes could experience the same traffic slow-down if congestion on the off-ramp spills over into the mainline.



2) Ala-13 PM R9.20, the southbound off-ramp to Broadway Terrace in Oakland. This is a fish hook ramp which experienced a lot of hits on the existing metal beam guard railing. Caltrans implemented many improvements including, additional warning signs - both ground mounted and overhead, rumble strips inside the lane. There will be a project to improve the super-elevation, widen left shoulder, and replace the existing metal beam guard railing with concrete barrier. **(Off-Ramp)**

Point of traffic detection: (Marked by a red box)

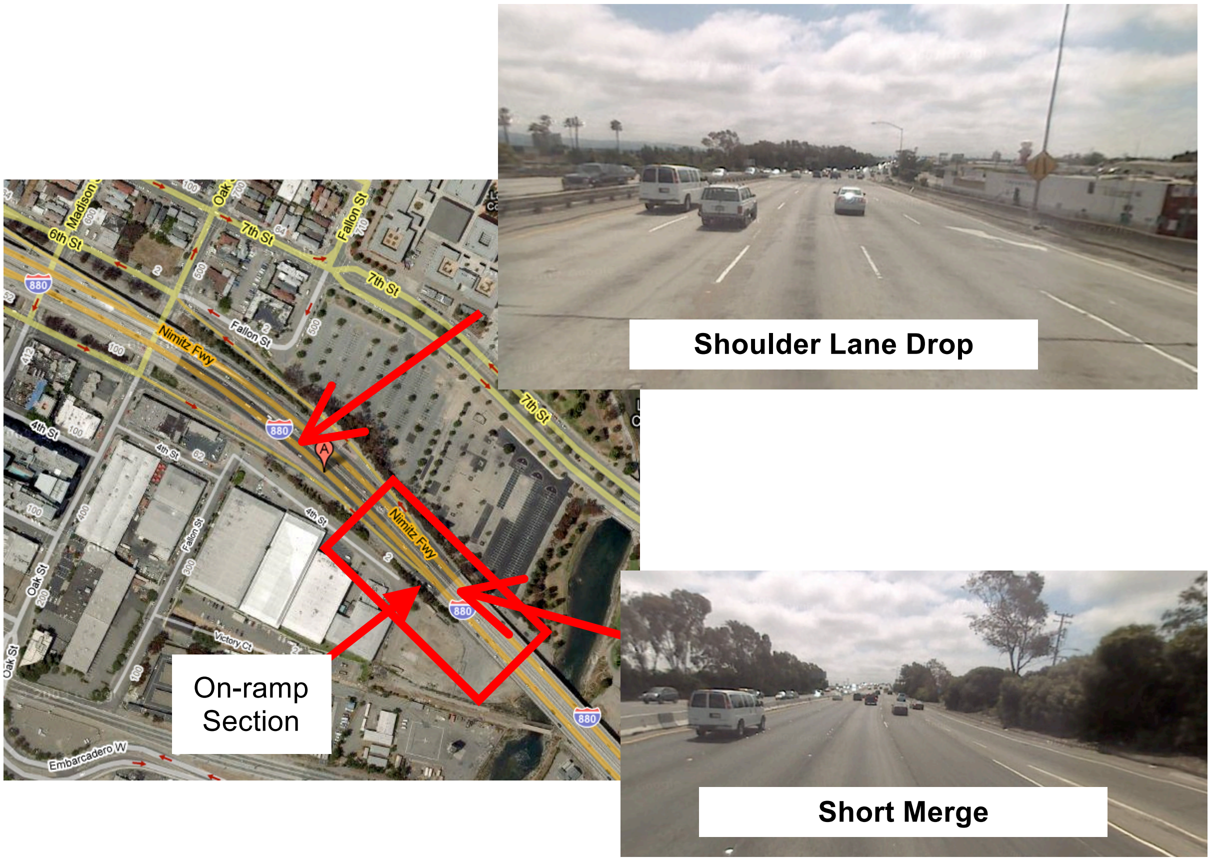
- Starting from the pin marker to a point upstream 100-200 yards, just slightly north of the overhead sign structure



3) ALA-880 PM 17.5, in southbound direction around merging area from 5th/Oak St. on-ramp. This location has the following features: **(Curved Section)**
i) Horizontally and Vertically Curved
ii) Poor visibility from High St. on-ramp and also from mainline
iii) Congested area during morning and afternoon commute hours

Point of traffic detection: (Marked by a red box)

- near the 5th/Oak St on-ramp merge
- Primarily interested for traffic queue on the right lanes, but the slow-down effect may be applicable to all lanes on the freeway.



4) ALA-880 PM 19.4, in northbound direction approaching Route 238 connector. Traffic from this ramp often backs onto freeway in the right lane. (This is not curved section.) **(Off-ramp bottleneck)**

Point of traffic detection: (Marked by a red box)

- The traffic queue build-up at this location could be 100-200 yards long or it could be one-mile long.
- The first candidate point for sensor installation will be 100 yard upstream (south) of the pin marker at the bottom of the picture.
- There is an existing SpeedInfo sensor (ID #9925) located about one mile upstream from this location, which may be applicable when traffic congestion is severe.

5) SF-280 PM R1.5, in northbound direction approaching the Geneva off-ramp in San Francisco. Traffic from this ramp backs onto freeway in the right lane. **(Off-ramp bottleneck)**

Point of traffic detection: (Marked by a red box)

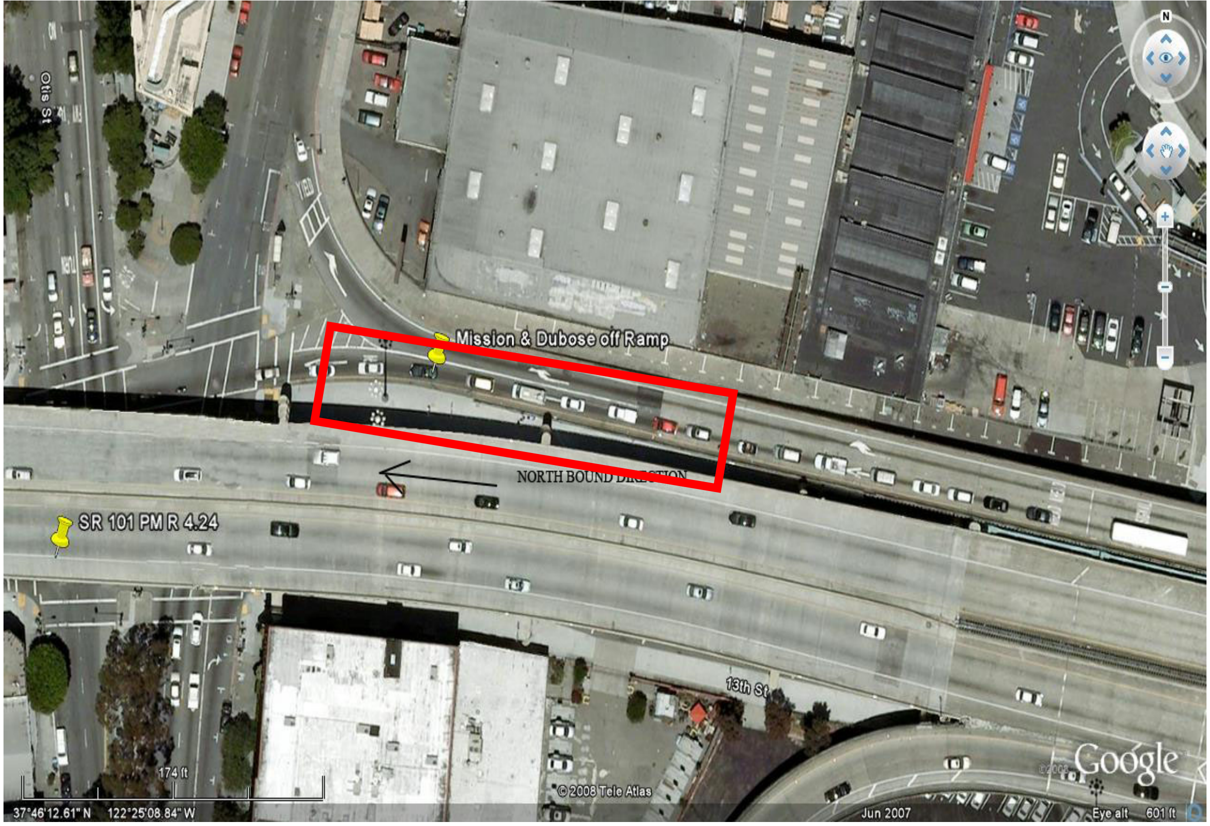
- 100-200 yards upstream of the beginning of the off-ramp, which will place it just off the lower edge of the picture below

6) SR101 Northbound Mission & Dubose off Ramp

The figure shows the section of State Road 101 Northbound and a section of off-ramp. The cross streets are Mission street and Dubose street.

Point of traffic detection: (Marked by a red box)

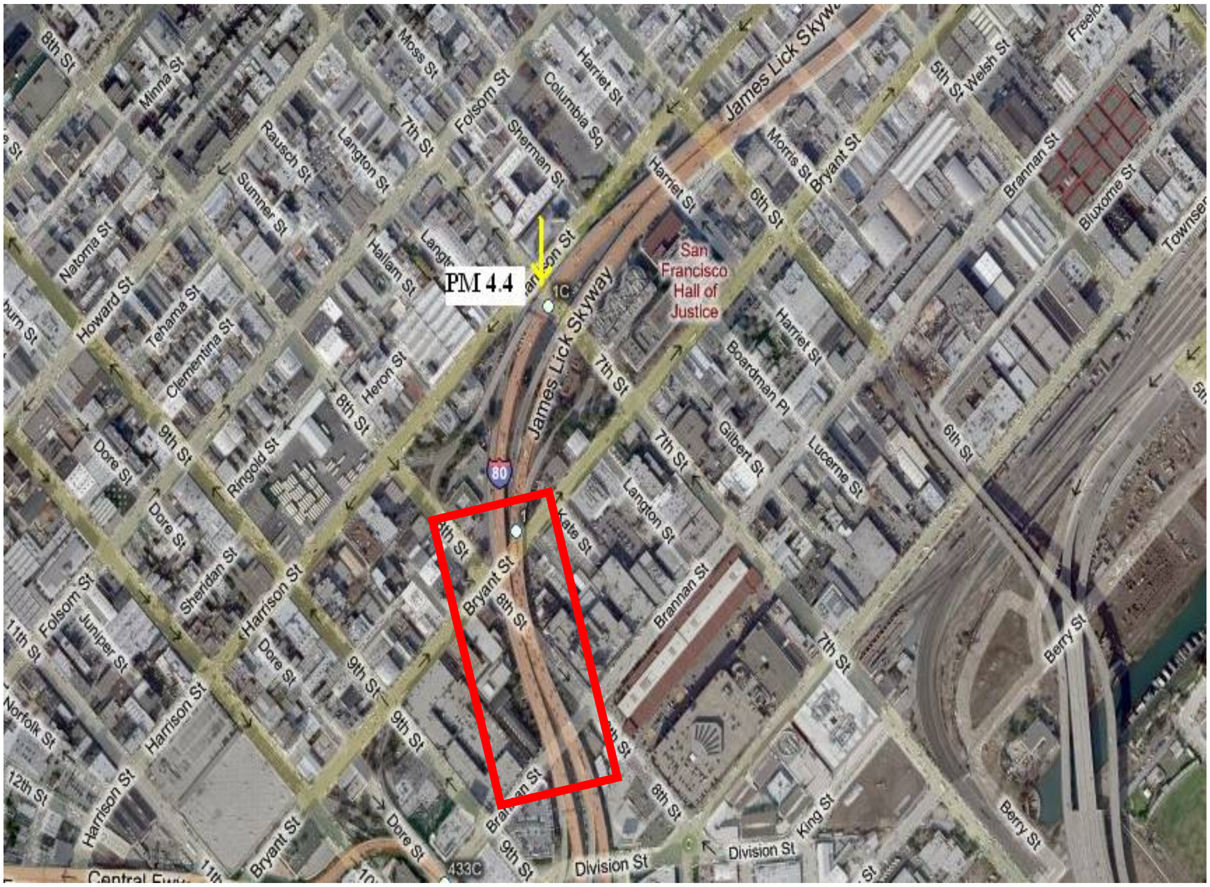
- The ending portion of the off-ramp (near the signal light at the local street), mainly to detect the stopped queue waiting at the signaled intersection
- The applicable length is about 100-200 yards.



7) San Francisco County, US-101, SB and NB PM 4-6 (Hospital Curve)

Point of traffic detection: (Marked by a red box)

- Due to a combination of curves and elevation changes, there is limited visibility from certain sections along the Hospital curve.
- The primary interest for this location is the slow queue around the curves in either direction



8) SCl-880 PM 4.1, in northbound direction approaching the connector to northbound Route 101. There is evidence that cars are hitting the k-rails on the left of this connector. **(Ramp)**

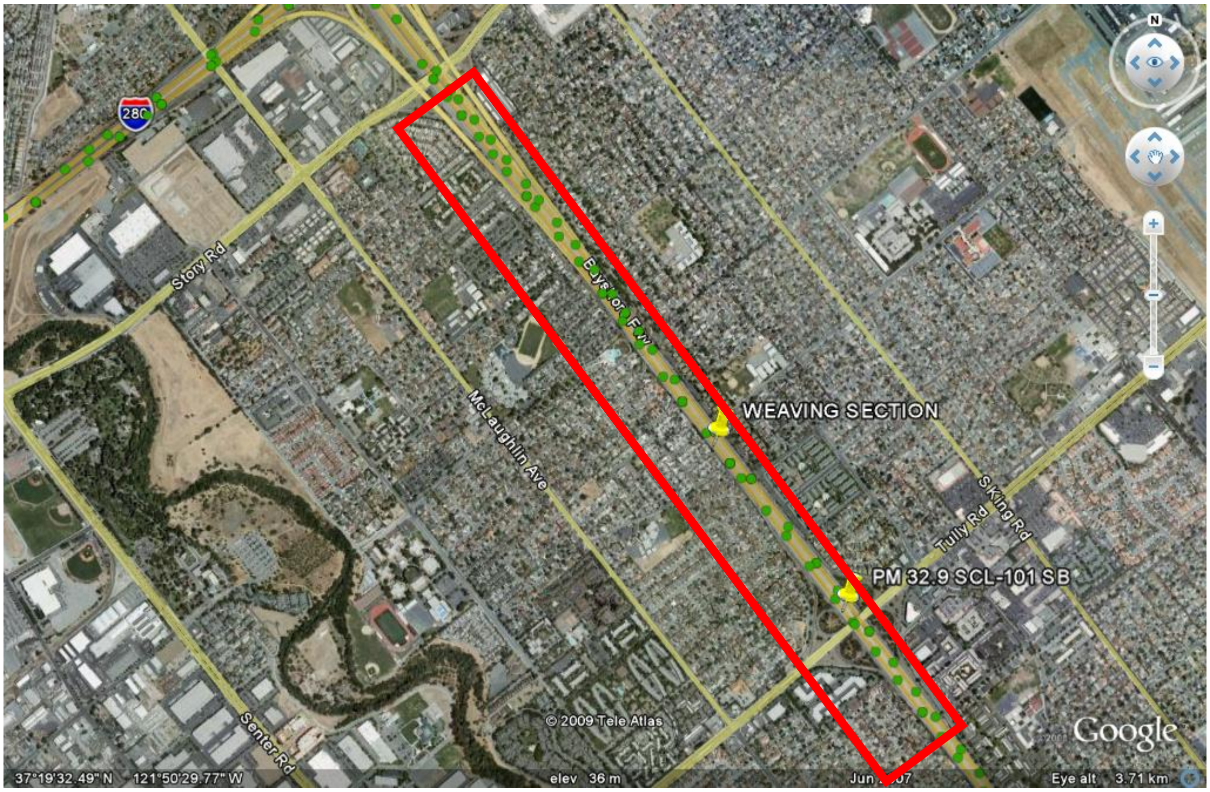
Point of traffic detection: (Marked by a red box)

- This site is focused on the clover-leaf circular connector from northbound 880 to northbound 101 to monitor the slow queue at the second half of the connector ramp
- PATH will determine if ramp metering has been implemented. If it has, this site will be dropped, and detection will not be needed.

9) SCl-101 PM 32.9, in southbound direction between Tully Road and Story Road. There is congestion during peak periods due to traffic weaving.

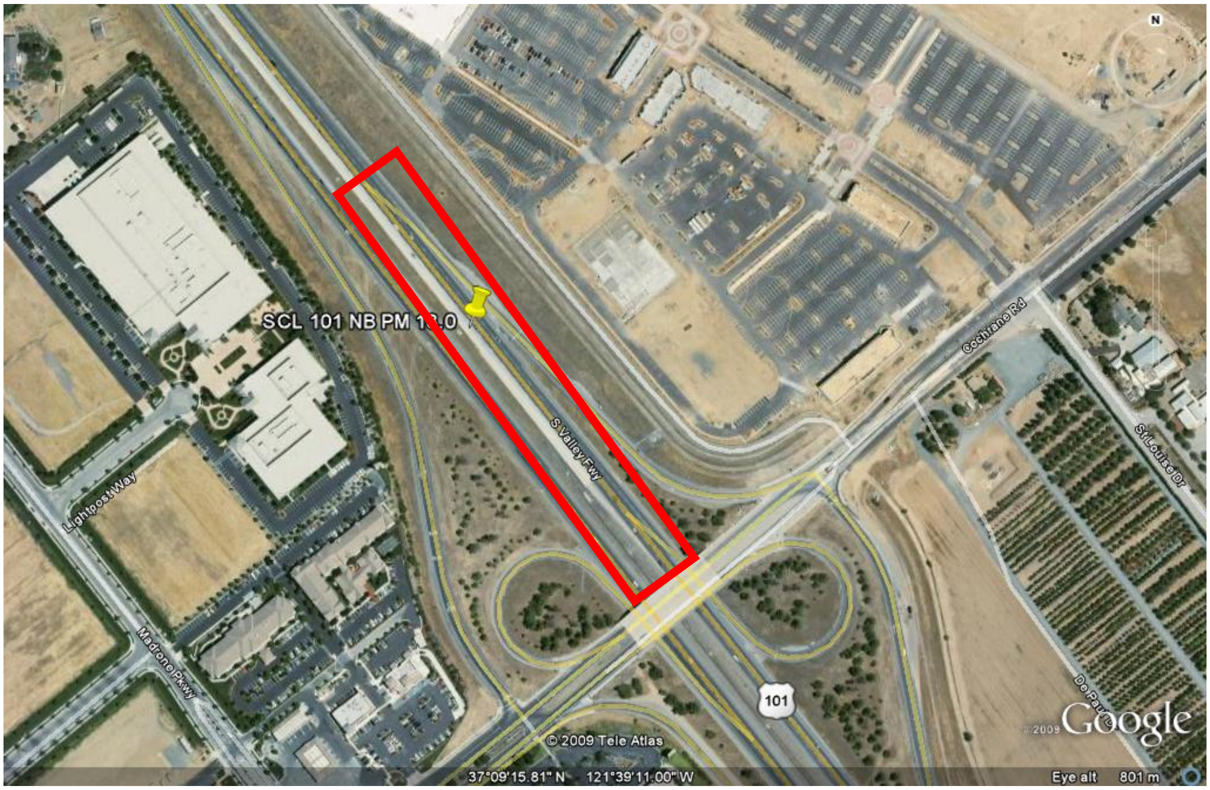
Point of traffic detection: (Marked by a red box)

- Considerable traffic weaving between two exits in congestion periods
- There is an existing SpeedInfo sensor (ID #7374) that may be applicable for this site.



10) Santa Clara County US-101, NB PM 18.0 Near Cochrane Interchange

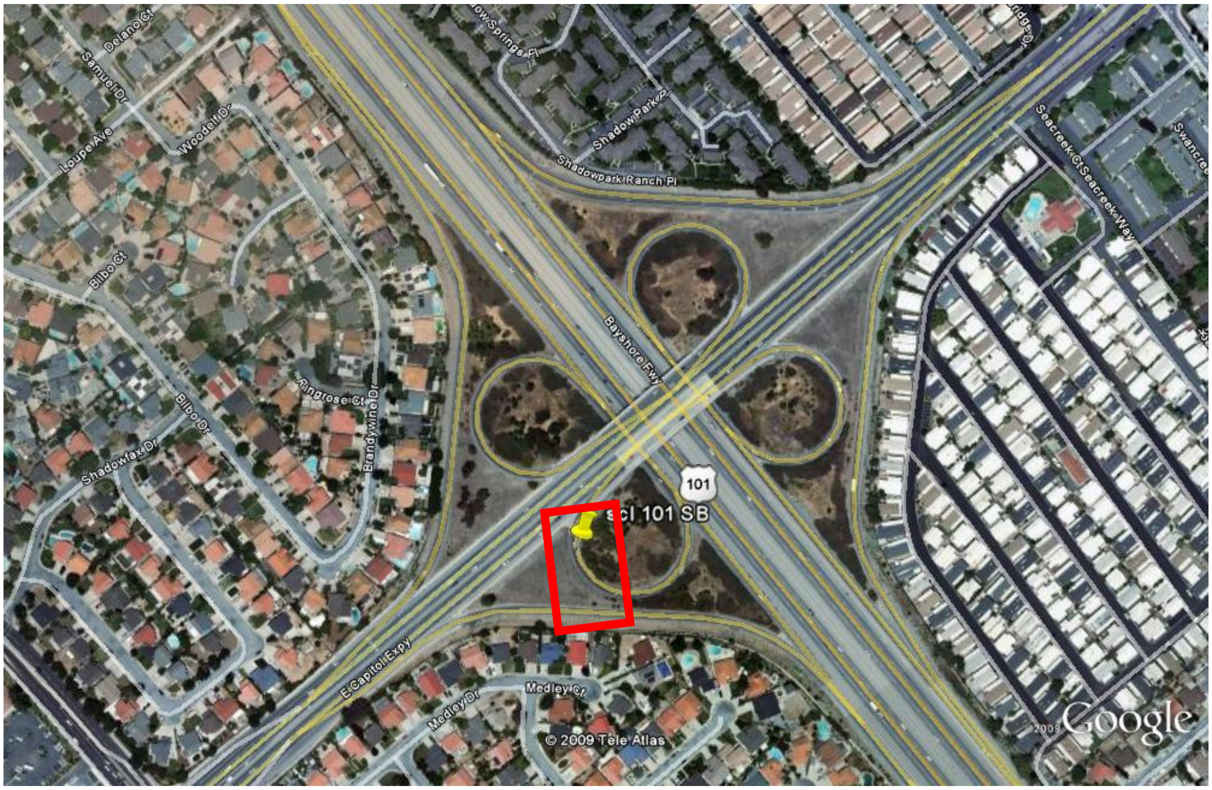
Point of traffic detection: (Marked by a red box)
- Near 60% of collisions on left lane
- Near Transition of 3-Lane into 4-lane segment with HOV lane on left



11) Santa Clara County US-101, SB Tully Road EB Exit

Point of traffic detection: (Marked by a red box)

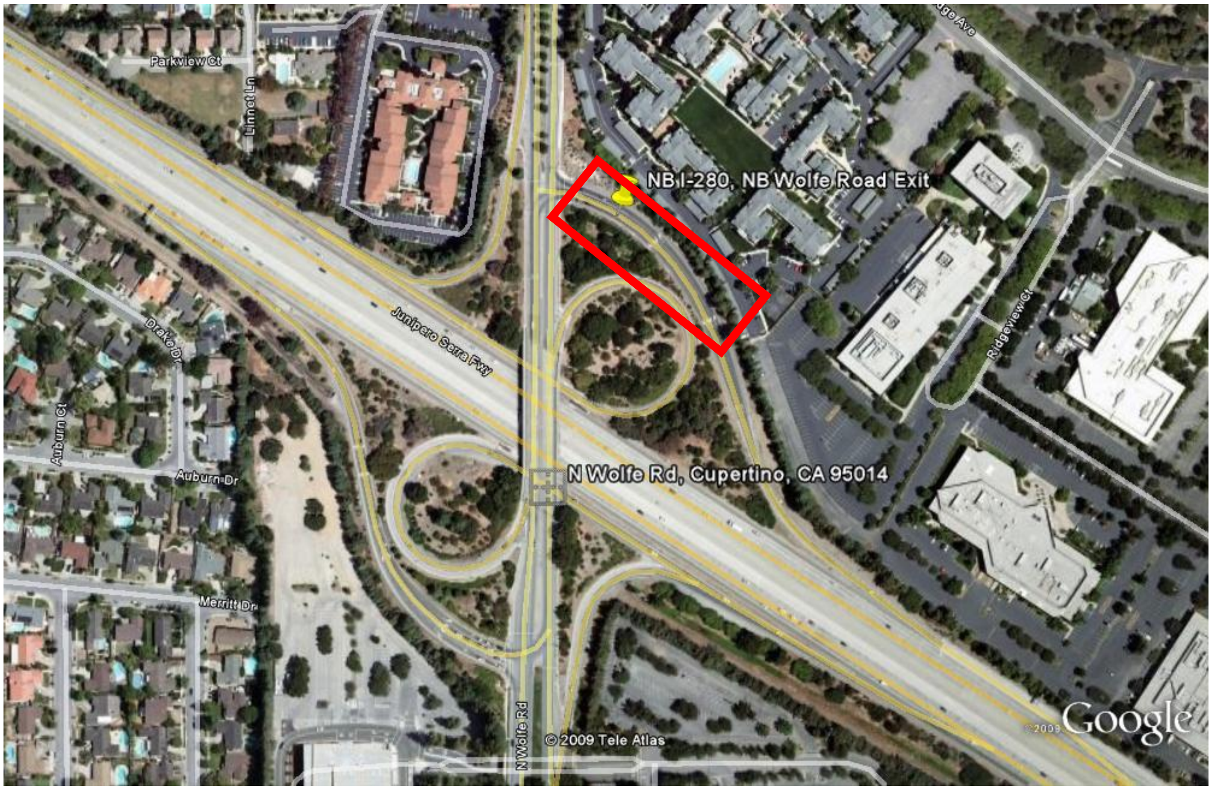
- This site is focused on the clover-leaf circular connector from southbound 101 to eastbound Tully Road to monitor the slow queue at the second half of the connector ramp



12) Santa Clara County NB I-280, NB Wolfe Road Exit

Point of traffic detection: (Marked by a red box)

- This site is focused on the ending portion of the off ramp, where traffic stops for traffic signals.
- There is limited visibility from the beginning of the off-ramp, such as a driver at the pin marker location..



13) CC-80 PM 3.4, in eastbound direction around weaving section between San Pablo Ave and Amador-Solano. This location has the following features: **(Curved Section)**

i) Horizontally and Vertically Curved
ii) Recurrent (head of) bottleneck location due to weaving traffic
iii) Visibility limited

Point of traffic detection: (Marked by a red box)

- Traffic build-up common between the exits of San Pablo Dam Road and Solano Ave on Eastbound I-80, slightly downstream from the section shown in the picture.
- Detection of queue needed at the curved section near the Solano Ave exit

APPENDIX B – DAS ENGINEERING DATA DEFINITIONS

Contents of the Engineering “a” File (Forward Looking Radar)

Column	Parameter	Units
1	Timestamp of File Write	hh:mm:ss:sss
2	Timestamp of Last Radar Data Read	hh:mm:ss:sss
3	Target 1 ID	(int)
4	Target 1 Range	0.1 ft
5	Target 1 Range Rate	0.1 ft/s
6	Target 1 Azimuth	0.002 rad
7	Target 1 Acceleration	LSB = 0.01ft/sec/sec
8	Target 1 Acceleration	LSB = 0.01ft/sec/sec
9	Target 2 ID	(int)
10	Target 2 Range	0.1 ft
11	Target 2 Range Rate	0.1 ft/s
12	Target 2 Azimuth	0.002 rad
13	Target 2 Acceleration	LSB = 0.01ft/sec/sec
14	Target 2 Acceleration	LSB = 0.01ft/sec/sec
15	Target 3 ID	(int)
16	Target 3 Range	0.1 ft
17	Target 3 Range Rate	0.1 ft/s
18	Target 3 Azimuth	0.002 rad
19	Target 3 Acceleration	LSB = 0.01ft/sec/sec
20	Target 3 Acceleration	LSB = 0.01ft/sec/sec
21	Target 4 ID	(int)
22	Target 4 Range	0.1 ft
23	Target 4 Range Rate	0.1 ft/s
24	Target 4 Azimuth	0.002 rad
25	Target 4 Acceleration	LSB = 0.01ft/sec/sec
26	Target 4 Acceleration	LSB = 0.01ft/sec/sec
27	Target 5 ID	(int)
28	Target 5 Range	0.1 ft
29	Target 5 Range Rate	0.1 ft/s
30	Target 5 Azimuth	0.002 rad
31	Target 5 Acceleration	LSB = 0.01ft/sec/sec
32	Target 5 Acceleration	LSB = 0.01ft/sec/sec
33	Target 6 ID	(int)
34	Target 6 Range	0.1 ft
35	Target 6 Range Rate	0.1 ft/s
36	Target 6 Azimuth	0.002 rad
37	Target 6 Acceleration	LSB = 0.01ft/sec/sec
38	Target 6 Acceleration	LSB = 0.01ft/sec/sec
39	Target 7 ID	(int)
40	Target 7 Range	0.1 ft
41	Target 7 Range Rate	0.1 ft/s
42	Target 7 Azimuth	0.002 rad
43	Target 7 Acceleration	LSB = 0.01ft/sec/sec
44	Target 7 Acceleration	LSB = 0.01ft/sec/sec

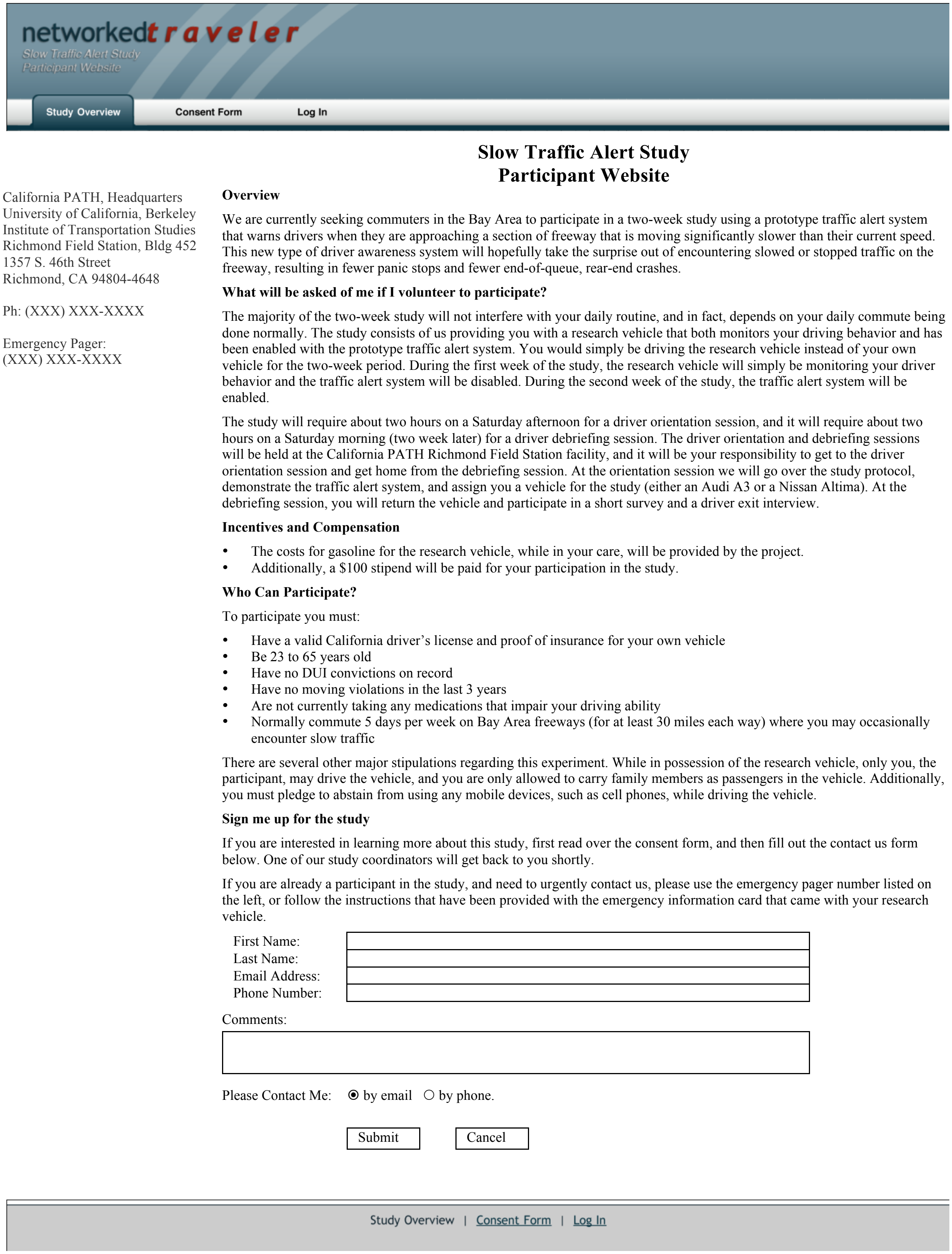
Contents of the Engineering “d” File (Driving Data)

Audi A3 Column	**Nissan Altima Column**	**Engineering Parameter**	**Format (Units)**
1	1	File Write Timestamp	hh:mm:ss.sss
2	2	Seconds Since Midnight	seconds
3	3	Seconds Since Data Recording Start	seconds
4	5	Brake (Off/On)	0/1
5		Audi Turn Lights (Off/Left/Right/EF)	(int)
6	7	Cruise Control	(int)
7	9	Gear	(int)
	10	Engine RPM	(int)
8	11	Turn Signals	(int)
9	12	Windshield Wiper	0/1
10	4	Ignition (Off/On)	0/1
11	-	Audi Brake Pressure	bar
12	-	Audi Acceleration X	g
13	-	Audi Acceleration Y	g
14	6	Throttle	0-100%
15	-	Audi Steering Angle	deg
16	8	Speed	km/h
17	-	Audi Yaw Rate	deg/s
18	13	UIMU Acceleration (Longitudinal)	g ($/9.1553*10^{-5}$)
19	14	UIMU Acceleration (Lateral)	g ($/9.1553*10^{-5}$)
20	15	UIMU Acceleration (Vertical)	g ($/9.1553*10^{-5}$)
21	16	UIMU Gyro (Body Roll)	deg/s ($/6.8665*10^{-3}$)
22	17	UIMU Gyro (Body Pitch)	deg/s ($/6.8665*10^{-3}$)
23	18	UIMU Gyro (Lateral Yaw)	deg/s ($/6.8665*10^{-3}$)
24	19	GPS UTC Seconds Since Midnight	seconds
25	20	GPS UTC Date	ddmmyy
26	21	GPS Longitude	degrees
27	22	GPS Latitude	degrees
28	23	GPS Speed (over ground)	m/s
29	24	GPS Heading	degrees
30	25	GPS Altitude (above sea level)	meters
31	26	GPS Number of Satellites	(int)
32	27	GPS POS (fix quality: invalid/gps/dgps)	0 / 1 / 2
33	28	GPS HDOP	(float)

Contents of the Engineering “x” File (Experiment Data)

Column	Parameter	Units
	System Timestamp Information	
1	File Write Timestamp	hh:mm:ss.sss
2	Seconds Since Midnight	seconds
3	Seconds Since Data File Started Recording	seconds
	NT Wireless Network Status	
4	Vehicle Timestamp of Last Server Message Received	seconds
5	Message Counter	(int)
	Vehicle/Participant Information	
6	Car ID	(int)
7	Participant ID	(int)
8	Date that Audible Alerts Start	MMDDYY
	NT Alert Information	
9	Alert Status (Uninitialized / No Alert / Too Soon / Baseline Triggered / Audible Triggered)	0/1/2/3/4
10	Warning Type (None / Slow Traffic Ahead / Slow Curve Left / Slow Curve Right)	0/1/2/3
11	Audible Alert Playing	0/1
12	Alert Suggested Speed (rounded to nearest 5 mph)	int
	Most Relevant Trigger Point	
13	Latitude	deg
14	Longitude	deg
15	Heading	deg
16	Average Speed at Trigger Point	mph
17	Distance to Trigger Point	miles
18	Current Heading Difference	deg
19	Current Speed Difference	mph

APPENDIX C – PARTICIPANT RECRUITMENT WEBSITE



Slow Traffic Alert Study
Participant Website

California PATH, Headquarters
University of California, Berkeley
Institute of Transportation Studies
Richmond Field Station, Bldg 452
1357 S. 46th Street
Richmond, CA 94804-4648

Ph: (XXX) XXX-XXXX

Emergency Pager:
(XXX) XXX-XXXX

Overview

We are currently seeking commuters in the Bay Area to participate in a two-week study using a prototype traffic alert system that warns drivers when they are approaching a section of freeway that is moving significantly slower than their current speed. This new type of driver awareness system will hopefully take the surprise out of encountering slowed or stopped traffic on the freeway, resulting in fewer panic stops and fewer end-of-queue, rear-end crashes.

What will be asked of me if I volunteer to participate?

The majority of the two-week study will not interfere with your daily routine, and in fact, depends on your daily commute being done normally. The study consists of us providing you with a research vehicle that both monitors your driving behavior and has been enabled with the prototype traffic alert system. You would simply be driving the research vehicle instead of your own vehicle for the two-week period. During the first week of the study, the research vehicle will simply be monitoring your driver behavior and the traffic alert system will be disabled. During the second week of the study, the traffic alert system will be enabled.

The study will require about two hours on a Saturday afternoon for a driver orientation session, and it will require about two hours on a Saturday morning (two week later) for a driver debriefing session. The driver orientation and debriefing sessions will be held at the California PATH Richmond Field Station facility, and it will be your responsibility to get to the driver orientation session and get home from the debriefing session. At the orientation session we will go over the study protocol, demonstrate the traffic alert system, and assign you a vehicle for the study (either an Audi A3 or a Nissan Altima). At the debriefing session, you will return the vehicle and participate in a short survey and a driver exit interview.

Incentives and Compensation

- The costs for gasoline for the research vehicle, while in your care, will be provided by the project.
- Additionally, a $100 stipend will be paid for your participation in the study.

Who Can Participate?

To participate you must:

- Have a valid California driver's license and proof of insurance for your own vehicle
- Be 23 to 65 years old
- Have no DUI convictions on record
- Have no moving violations in the last 3 years
- Are not currently taking any medications that impair your driving ability
- Normally commute 5 days per week on Bay Area freeways (for at least 30 miles each way) where you may occasionally encounter slow traffic

There are several other major stipulations regarding this experiment. While in possession of the research vehicle, only you, the participant, may drive the vehicle, and you are only allowed to carry family members as passengers in the vehicle. Additionally, you must pledge to abstain from using any mobile devices, such as cell phones, while driving the vehicle.

Sign me up for the study

If you are interested in learning more about this study, first read over the consent form, and then fill out the contact us form below. One of our study coordinators will get back to you shortly.

If you are already a participant in the study, and need to urgently contact us, please use the emergency pager number listed on the left, or follow the instructions that have been provided with the emergency information card that came with your research vehicle.

First Name:
Last Name:
Email Address:
Phone Number:

Comments:

Please Contact Me: ● by email ○ by phone.

APPENDIX D – PARTICIPANT CONSENT MATERIALS

Consent to Participate in the Networked Traveler Driving Situational Awareness Application Field Experiment

Introduction

Welcome to the California PATH (Partners for Advanced Transit and Highways) Research Program at the University of California, Berkeley. We appreciate your willingness to learn about and potentially participate in this study on driving behavior. This research project is under the direction of Professor XXXXXXXX, who is a Professor of Civil Engineering at U.C. Berkeley. It is sponsored by Caltrans in partnership with the U.S. Department of Transportation and in collaboration with SAIC International, which is a consulting company that serves as an independent evaluator for this research project.

Purpose

In this research study, we are collecting data on how people react to, and what people think of, a new type of driver awareness system that has been proposed for automobiles. Specifically, we are studying whether or not drivers can benefit from an alert that warns you when you are rapidly approaching a section of freeway where the traffic ahead has slowed or stopped. The goal of this type of system is to provide you with preview of what will happen on the road ahead. As an example, if you were travelling at 65 mph and approaching an area where traffic had slowed to 25 mph, about 1 mile before reaching the slowed traffic, the system will play an auditory alert saying that you should prepare for slow traffic ahead. Hopefully, the system will take the surprise out of encountering slowed or stopped traffic on the freeway, resulting in fewer end-of-queue, rear-end crashes. We believe this is important research that will contribute to enhancing automobile safety and comfort in the future, and our goal in conducting this research is to ensure that these types of new systems are designed with drivers in mind.

Procedures

To be eligible for this study, we must ask for your permission to inspect your driving record. We will look only for information about Driving Under the Influence (DUI) convictions or moving violations less than three years old. Our copy of your driving record, and of the information used to obtain it, will be destroyed if you decide not to participate in the study, or if you decide to participate in the study, it will be destroyed within 30 days of completing the study.

If you decide to participate in this study, we will be providing you with a California PATH research vehicle, equipped with the slow-traffic-ahead warning system, for you to drive as your own for a period of about two weeks. The study itself will consist of three parts. First, there will be a driver orientation session. Second, there will be two weeks of driving the provided research vehicle in the study, and third, there will be a driver debriefing session. While in possession of the research vehicle and during the bulk of the two weeks of the driving study, you will only be asked to drive the research vehicle as you would normally drive your own vehicle, using it for your daily commutes and in your daily routine. Aside from the driver orientation session at the beginning of the study and the driver debriefing session at the end of the study, participation in the study should result in minimal interference with your daily routine.

The driver orientation session will be scheduled with you in advance, and it will last for two hours, typically occurring on a Saturday afternoon at the California PATH Richmond Field Station facility. You will be responsible for getting yourself to the orientation session so that you can drive the research vehicle home. During this session we will ask you to read, ask questions about, and sign this consent form, and fill out a short driver background information survey. We will demonstrate how the warning system works, answer any questions regarding the study protocol, assign a research vehicle to you, and go over the location of all of the controls in the vehicle. After the orientation session, you will be free to drive the vehicle home and start the study.

The driving portion of this study will last for approximately two weeks and is being conducted naturalistically, meaning that you are to use the vehicle as you would your own in the course of your normal daily activities. In this study, for the first 7 days, the vehicle will simply be monitoring your driving and will not be providing any slow-traffic alerts. For the second 7 days of the study, the vehicle’s traffic alert system will be enabled, and it will be providing you with slow-traffic alerts. Additionally, once you have received alerts, you will be able to log into the research study website (after you have finished driving), review your alerts, and provide us with feedback on any individual alerts that your received. This short survey takes no more than a few minutes to answer for each alert.

While you are driving the research vehicle, your driving behavior will be monitored by the data and video recording systems that have been installed in the vehicle. The data recording system records parameters such as throttle use, braking, speed, acceleration, following distance to the vehicle in front of you, and vehicle location through GPS. The data recording system also records the conditions that triggered any slow traffic alerts that you might have received. The video recording system records from three cameras, one facing forward aimed at the road scene, one facing you, the driver, and one facing rearward to view traffic behind you.

On the last day of the study, typically a Saturday morning, there will be driver debriefing session that will last for approximately two hours. You will bring the research vehicle back to the California PATH Richmond Field Station facility to turn in the vehicle. At this point in time you will have one last chance to log into the research study website and comment on any of the alerts that you received, before participating in an exit interview. After the exit interview, you will be responsible for arranging for your own transportation back home.

Research Vehicle Restrictions

Vehicle insurance coverage will be provided by the University of California as long as the vehicle is used in compliance with the restrictions outlined below. If you violate any of the laws of California or the terms outlined below while driving the research vehicle, the University’s vehicle insurance coverage may not be in effect and you may be held liable for any damages. While in possession of and using the research vehicle that is provided to you by California PATH, you must agree to the following conditions:

1. I, the participant, will be the only person to drive the vehicle
2. I, the participant, will not carry any passengers in the research vehicle except for family members
3. I, the participant, will operate the vehicle in accordance with all traffic laws
4. I, the participant, will not drive the research vehicle while impaired by alcohol, prescription medication, over-the-counter medication, or any controlled substances
5. I, the participant, will not take the vehicle outside of the continental United States
6. I, the participant, will be the sole individual responsible for all tolls, tickets, and/or violations received for the duration during which the research vehicle is assigned to me
7. I, the participant, will report as early as possible to PATH any problems, mechanical malfunctions, accidents, or damage sustained to the vehicle
8. I, the participant, will pledge to abstain from using my personal cell phone while driving the research vehicle

Effective January 1, 2009, California SB 28 banned texting while driving and limited cell phone use while driving to hands-free devices only. On October 1, 2009, President Obama issued an executive order directing the federal government to take a leadership role in reducing the problem of distraction while driving. Recent studies have concluded that distraction may be a factor in over 5000 fatalities and 500,000 injuries on our nation's highways each year. To promote awareness of the problem of distracted driving, we are asking all participants of this study to go a step beyond the law and abstain from all cell phone use while driving during their two weeks in the study.

Benefits

There is no direct benefit to you from the research. We hope that the research will benefit society by improving our knowledge about driver behavior and using this knowledge to improve the development of advanced transportation concepts and prototypes.

Risks

This study presents minimal risk to you. At no time during this study will you be asked to drive in unsafe conditions, perform any unsafe driving actions, or will you be asked to drive in any situations where you do not feel comfortable. However, since the study involves driving a car, there is always the potential for a crash, and with all research, there is always a risk of a breach of confidentiality.

Confidentiality

This research vehicle is equipped with a number of passive monitoring systems that allow us to measure driver behavior, including video cameras that will record both the front and rear scenes as well as recording images of you, the driver, at all times. We will use these video recordings in order to assess the type of traffic you were in, what kind of reactions you had when the warnings were given, and to make sure that you are the driver using the vehicle during the days the vehicle will be under your care. You have the right to restrict (at any time) the use of your video recordings, and you can specify the allowable uses of the video by filling out the attached video release form.

All of the information that we obtain from or about you during the research will be kept confidential. We will not use your name or identifying information in any reports resulting from this research. We will protect your identity and the information that we collect from you to the full extent of the law (this does not include subpoena). Should you be involved in an accident while driving the study car, the video recordings taken may be subpoenaed as evidence.

This project includes collaboration with an independent evaluator, and that evaluator has pledged to protect any data that is shared with them to the same extent as described above. Furthermore, after this project is completed, we may make the data collected during your participation available to future researchers for use in future research projects. If so, we will continue to take the same precautions to protect your confidentiality and preserve your identity from disclosure.

Compensation

You will be paid a total of $100 for your participation. If you decide to withdraw from the study before its completion, you will be paid a prorated amount based on the extent of your participation. Fuel costs will either be reimbursed at the end of your participation with receipts, or you may be provided with the option to use a fuel card. If you choose this option, you will be asked to sign a fuel card user agreement form.

Treatment and Compensation for Injury

If you are injured as a result of taking part in this study, care will be available to you. The costs of this care may be covered by the University of California depending on a number of factors. If you have any questions regarding this assurance or regarding your rights or treatment as a participant in this study, you may consult the Committee for Protection of Human Subjects, University of California, 2150 Shattuck Avenue, Rm. 313, Berkeley, CA 94704-5940, PH: XXX-XXX-XXXX, email: subjects@berkeley.edu.

Rights

Your participation in this research is voluntary. You are free to refuse to take part, and you may stop taking part at any time. If you have any questions about the research, you may contact the study coordinator, XXXXXXXX, at California PATH, PH: (XXX) XXX-XXXX. You may also request a copy of this consent form for you records.

I have read and understood this consent form, and I agree to take part in the research.

____
Participant's Name (Please Print)

____________________________________ ________________
Participant's Signature Date

____________________________________ ________________
PATH Researcher Obtaining Consent Date

Consent for Electronic DMV Records Check

By providing California PATH with the information below, I authorize California PATH, UC Berkeley, to use my personal information to check my DMV record using the online, third-party service, Volunteers Select Plus, offered by Choice Point. The company's privacy policies are available for you to review at the following websites:

http://www.volunteerselectplus.com/	http://www.privacyatchoicepoint.com/

The DMV record report generated by ChoicePoint will only be used to verify your eligibility to volunteer for this study. The researchers at California PATH can, at your request, provide you with a copy of the results of your electronic DMV records request. You also have the right under Section 1786.22 of the California Civil Code to contact ChoicePoint directly during normal business hours to obtain your file for your review. You may obtain such information as follows:

1. In person at a ChoicePoint office. You will need to furnish proper identification prior to receiving your file. You may have someone accompany you and should inform such person that they will also have to present reasonable identification. If you want ChoicePoint to disclose to or discuss your information with this third party, you may be required to provide a written statement granting ChoicePoint permission to do so.
2. By certified mail, if you make a written request (and provide proper identification) to have your file sent to a specified addressee.
3. By telephone, if you have previously made a written request and provided proper identification.

Electronic copies of our DMV records stored on ChoicePoint's servers are deleted 30 days after being requested. The information that you provided below and any electronic or paper copies of your DMV records held by California PATH will be destroyed 30 days after your participation in this research has been completed.

Name	
Address	
Date of Birth	
Social Security Number	
Driver's License Number	

Participant's Signature ______________________ Date __________

☐ The participant provided the information above and consented to allow California PATH to perform the DMV record screening either by email (attached) or verbally over the phone.

PATH Researcher Obtaining Consent ______________________ Date __________

PHOTOGRAPHIC, AUDIO, AND/OR VIDEO RECORDS RELEASE CONSENT FORM

As part of this project we will have made photographic, audio, and/or video recordings of you while you participated in the research. You have the right to restrict the use of the recordings made during this experiment, and you have the right to change your mind as to the extent of those restrictions or limitations. Release of your recorded images (beyond question 1) is not a requirement to participate in this test.

Please indicate below, the authorized uses of your photographic, audio, and video recordings. Although your name and personal information will always be kept confidential, whenever consent is granted to release your recordings, there is the chance that someone may be able to identify you based on your image. When possible, if the participant's face is not crucial to the point being made in the report or presentation, we will blur your face.

1. The records can be studied by research teams for use in this research project and future research projects.

   Photo: __________ Audio: __________ Video: __________
   initials *initials* *initials*

2. The records can be shown to subjects in other experiments.

   Photo: __________ Audio: __________ Video: __________
   initials *initials* *initials*

3. The records can be used for scientific publications.

   Photo: __________ Audio: __________ Video: __________
   initials *initials* *initials*

4. The records can be shown at meetings of scientists interested in the study of driving behavior

   Photo: __________ Audio: __________ Video: __________
   initials *initials* *initials*

5. The records can be shown in classrooms to students.

   Photo: __________ Audio: __________ Video: __________
   initials *initials* *initials*

6. The records can be shown in public presentations to nonscientific groups.

   Photo: __________ Audio: __________ Video: __________
   initials *initials* *initials*

7. The records can be used on television and radio.

   Photo: __________ Audio: __________ Video: __________
   initials *initials* *initials*

I have read the above descriptions and given my consent for the use of the records as indicated above.

______________________________________ ______________
Participant's Signature Date

University of California, Berkeley
Fuel Card Agreement Form

For the purpose of the data collection that you have agreed to participate in, you have been entrusted with the use of a U.C. Berkeley Fuel Card which can be used for fueling the research vehicle that is being provided to you. The conditions of use and your role as a card user are detailed below.

Fuel Card User

The Fuel Card User assumes responsibility for the physical security of a State of California Fuel Card (Voyager Card) and its PIN (Personal Identification Number). The Fuel Card User assumes responsibility for all card transactions during the time frame when the card is in their possession. These transactions can be audited for appropriate use. If there are improper charges, see below, the participant is financially responsible to repay California PATH for those charges.

The Fuel Card User shall:

- Ensure physical security of Fuel Card. The card may **not** be left in the custody of a vendor.
- Do **not** record the PIN on the fuel card, card jackets, or other documents stored with the card.
- Ensure all transaction receipts are kept and provided with the return of the card.
- Report if the card is lost or stolen immediately (within 24 hours).

A Voyager Fuel Card can be used to purchase:

- Fuel, oil, coolant, and other fluids
- **In out-of-area emergencies only:** parts and labor for towing, road service, and mechanical repairs. (If possible, verify with PATH researchers first.)

A Voyager Fuel Card should *NOT* be used to purchase:

- Food or beverages.
- Parts and labor for towing, road service, and mechanical repairs within range of our local vendors (Berkeley, Oakland, Albany, Emeryville). In these situations, please use the agreements with our local vendors. Details are provide in the vehicle handbook located in the vehicle's glovebox.
- Other goods or services.

Agreement

In reference to the card listed below, I agree with the responsibilities and guidelines outlined above and as stated on the Fuel Card Control/Transaction Limit information sheet.

Participant's Name (*Please Print*) ______________________

Voyager Fuel Card Issued ______________________

Participant's Signature ______________________

Date __________

PATH Fuel Card Custodian's Signature ______________________

Date __________

APPENDIX E – VEHICLE CHECKLISTS

Vehicle Checkout Checklist

Vehicle Description				
Date Loaned		Vehicle Mileage		Subject #

☐ Demonstrate the "Slow Traffic Ahead" alert using the trigger point at the Richmond Field Station. Let subjects drive it themselves if they like.

☐ Walk around vehicle to inspect for damage. Note any pre-existing damage on the back of this form. Show subject how to open gas cap.

☐ Explain proximity key on the Nissan Altimas (for entry and starting the vehicle).

☐ Have subject start vehicle, adjust the seat, and adjust the mirrors.

☐ Show subject the location in the glove box where the owner's manual, vehicle registration, insurance card, accident instruction kit, and PATH contact info are kept.

☐ Show subject where lights and wiper controls are located.

☐ Show basic radio, climate controls.

☐ On the Nissan Altima's and the Red Audi A3, go over basic navigation system usage. Show them the PATH entry in the address book.

☐ Ask the participant if they have any other questions, and when finished, remind the test participants of the following:

- The test participant is the only one authorized to drive this vehicle.
- The test participant should not have any passengers other than immediate family.
- Use the car as they would use their own vehicle normally.
- When they receive alerts that are particularly noteworthy, remember to go to the NetworkedTraveler.org website to provide feedback.

☐ Schedule a return date & time with the participant

Return Date		Return Time	

Test Participant

Experimenter

Vehicle Return Checklist

Vehicle Description		
Date Returned	Vehicle Mileage	Subject #

☐ ____________ Initial — Visual inspection for vehicle damage
  - Ask returning participant to check the vehicle for any personal items

☐ ____________ Initial — Get fuel card & receipts: Document on subject payment form

☐ ____________ Initial — Take participant to B180
  - Fill out any last per alert surveys on-line
  - Exit Interview
  - Payment Form

☐ ____________ Initial — Download Data

☐ ____________ Initial — Check free disk space on both the engineering and video computers
  - Clear disk space if necessary

☐ ____________ Initial — Check tires pressures and inflate if necessary.

☐ ____________ Initial — Check oil, coolant, or any other fluid levels.

☐ ____________ Initial — Top off windshield washer fluid.

☐ ____________ Initial — Verify that headlights, tail lights, and turn signals are all working.

☐ ____________ Initial — Check glove box
  - Verify that insurance card and vehicle registration are *current*
  - Verify PATH emergency procedures & contact info card

☐ ____________ Initial — Clear navigation System Address Book and Previous Destination List
  - Put PATH RFS Address into Nav Address book

☐ ____________ Initial — Wash & vacuum & clean interior

☐ ____________ Initial — Fill car with gas.

____
Experimenter to Verify that Checklist is Complete

APPENDIX F – ADDITIONAL PROJECT PUBLICATIONS

The following is a list of publications that were generated by U.C. Berkeley faculty and students and California PATH researchers during the SafeTrip-21 Initiative which were not necessarily directly related to the foresighted driving field experiment which is described in this report.

Manasseh, C., Fallah, Y., Sengupta, R., and Misener, J. (2010). Learning User Perception to Traveler Situation Awareness Alerts on Mobile Devices. *Proceedings of the 17th World Congress for Intelligent Transport Systems and Services.* Busan, Korea, October 25-29.

Chan, C.Y., Manasseh, C., and Rezaei, S. (2010). Experimental Design and Evaluation of Networked Traveler Field Tests of Safety Applications in California. *Proceedings of the 2010 IEEE Intelligent Vehicles Symposium*. San Diego, CA, June 21-24. Los Alamitos, CA: IEEE.

Manasseh, C., Fallah, Y., Sengupta, R., and Misener, J. (2010). Using Smartphones to Enable Situation Awareness on Highways. *Proceedings of ITS America's 20th Annual Meeting and Exposition*. Houston, TX, May 3-5. Washington, D.C.: Intelligent Transportation Society of America.

Chan, C.Y., Misener, J., VanderWerf, J., and Jang, K. (2009). Safety Advisory Applications for Connected Traveler – Safe Trip 21 In California. *Proceedings of the 16th World Congress for Intelligent Transport Systems and Services.* Stockholm, Sweden, September 21-25.