

ANALYZING THE USE OF PORTABLE ADVANCED
TRAVELER INFORMATION SYSTEMS

by

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of the requirements for the degree

of

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in

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ABSTRACT

Advanced Traveler Information Systems (ATIS) have been employed over the past two decades to provide travelers with real-time traffic information; one example estimated downstream travel times. Portable ATIS, in the context of this study, can provide real-time traffic information—including advanced travel times, delay times, and reduced average speeds—to motorists by updating portable changeable message signs in rural settings. Currently, there are limited numbers of demonstrations of the capabilities of portable ATIS.

This paper summarizes the results of a portable ATIS demonstration project in Redding, California. For the demonstration, four different portable ATISs were deployed on a construction project for a two-week period. These systems included Blufax, iCone, License Plate Reader (LPR) and Adaptir. Three aspects were tested: accuracy, reliability, and usability. Accuracy was evaluated by comparing measured travel times and speeds with a stopwatch measured baseline. Reliability was assessed by monitoring and summarizing the maintenance needs during the demonstration. System usability was addressed in terms of ease of setup and calibration.

Overall, the systems accurately estimated travel times within 10 seconds 98 percent of the time for the LPR system and 100 percent of the time for the Blufax, and speeds were within 10 mph 99 percent of the time for the iCone and Adaptir systems. Each of the systems had their own unique challenges with reliability and usability. The results of this study show the promise of using portable systems to measure and display real-time travel times and highlight the challenges that need to be addressed for successful implementation.

The study plan for follow up studies summarize the implementation of a future research study that will focus on remedying the downfalls found from the original demonstration project as well as focus on a human factors related experiment measuring vehicle headways with different changeable message sign sequences. These study plans were not implemented but are provided to guide future research work.

CHAPTER 1

INTRODUCTION

This chapter includes the research topics and the organization of the entire paper. First, a background of the research topic will be discussed. Next, the problem statement and research objectives will be stated. An overview of the hypothesis statements and research importance is provided. Finally, an overall thesis organization will be presented.

Background

Advanced Traveler Information Systems (ATIS) have been employed over the past two decades to provide travelers with real-time traffic information. ATIS can be defined as any equipment with the capacity to capture real-time traffic information and relay that info to the driver. Many of the efforts have focused on using a fixed system, which provides timely traffic information at locations with recurring problems such as peak hour congestion. Motorists whose routes are disrupted by special events, natural disasters, or construction projects may be better served with a portable ATIS that can be rapidly deployed. For this specific report, portable ATIS provides real-time traffic information--including advanced travel times, delay times, and reduced average speeds--to motorists by updating portable changeable message signs (PCMS) with real-time messages.

Portable ATIS can be further be broken into dynamic speed reduction systems (DSRS) and portable traveler delay systems (PTDS). DSRSs can be defined as a radar system that provides a dynamic individual vehicle speed. Previous research has shown that these systems are proven to reduce driver speeds. Current research in DSRS is

undertaking the human factor connection between message sequences provided and the amount of speed reduction. This is further discussed in the Human Factors in ATIS section of Chapter 2, Literature Review. PTDSs can be defined as systems that detect downstream delay in terms of speed or travel time, and inform the motorist through a PCMS. Current research, as portrayed in this report, is focused on testing the reliability and accuracy of these systems. This is further discussed in the ATIS section of Chapter 2, Literature Review.

California Department of Transportation (Caltrans) initiated a research project to further investigate portable ATIS for possible future implementation. The project has reviewed existing best practices, interviewed practitioners, and identified and reviewed off-the-shelf technology for ATIS selection. This document summarizes the efforts and results of a portable ATIS demonstration project in Redding, California.

For the demonstration, four different portable ATISs were deployed on a construction project in Redding, California for a two-week period. Three aspects of the portable ATIS were tested: accuracy, reliability, and usability. Accuracy was evaluated by comparing travel time and speed measured across the different systems and with a measured baseline. Reliability was assessed by monitoring and summarizing the failures and needed maintenance for the systems during the demonstration. System usability was addressed in terms of ease of setup and calibration defining the setup person as the user.

Human factors issues with portable ATIS, and more specifically changeable message signs (CMS), were also investigated. Limitations of the current demonstration effort and subsequent future research were identified during this project. A research

experiment design was developed to test the effectiveness of different message sequences a CMS uses and more accurately measure the impacts of portable ATIS.

Problem Statement

Non-recurring congestion accounts for approximately half of all traffic congestion. This specific type of congestion introduces several safety hazards to drivers from the large amount of irregular traffic volumes from special events and other functions. With the use of portable ATIS, drivers alerted to traffic delay may be less anxious because of advanced knowledge and/or drive more cautiously. With advanced traffic knowledge, drivers may select less congested routes creating a more efficient transportation system for everyone.

Currently, there is a lack of research in the implementation of portable ATIS as there have been only a limited number of demonstrations of its effectiveness. Regardless of the magnitude of the benefits of portable ATIS, they will not be realized unless the systems are accurate, reliable, and usable.

Research Objectives

The objectives of this research are to evaluate the accuracy, reliability, and usability of portable ATISs through a real world demonstration. This knowledge will eventually help agencies and organizations assess the potential of portable ATIS.

Hypothesis Statements

For this experiment, accuracy, reliability, and usability of four portable ATISs were investigated. Previous research indicates different portable ATIS may have different levels of accuracy. ATISs may be unreliable in a portable setting.

Accuracy is important to increase the drivers' confidence in the system. If a portable ATIS provides inaccurate traffic information, drivers' frustrations and aggressions may not be reduced. Accuracy is also important to Caltrans or other deploying agencies. The public perception of Caltrans could be jeopardized if they implement an inaccurate portable ATIS. Accuracy is defined as the ability to measure actual travel times or speeds. Error is defined as the difference of the measured value by portable ATIS and some baseline. For this experiment, individual errors were used to generate proportions of time the error was greater than some acceptable threshold. As discussed further in Chapter 4, the proportion of time the portable ATIS is erroneous yields more usable results than a comparison of means. The thresholds of acceptable error in travel time and speed as measured by portable ATIS were set at 10 seconds and 10 miles-per-hour, respectively. These thresholds were provided from Caltrans and researchers.

It is assumed all four investigated ATISs will be accurate to available baselines in the portable setting for the entirety of the two-week deployment. The null hypothesis for this research is that 100 percent of errors in travel time and spot speed systems' data are less than or equal to 10 seconds and miles-per-hour, respectively. The hypothesis statement is:

$$H_0: P_{10} = 100\% \quad \text{Eq. 1}$$

$$H_1: P_{10} < 100\% \quad \text{Eq. 2}$$

Where,

P_{10} = Proportion of data with error \leq 10 mph or sec

Reliability is defined as the ability for a portable ATIS to remain online for the entirety of the two-week deployment. It is important for portable ATISs to be reliable and remain online to provide traffic information. The null hypothesis for this research is that there will be no breakdowns or gaps in data collection for the portable ATISs during the demonstration. The alternative hypothesis is there will be breakdowns and gaps in data collection of the portable ATISs during the demonstration. Due to the short demonstration period, no statistical significant conclusions were drawn from the reliability analysis. Data on how long systems ran before failing is reported in Reliability Results section.

Usability is defined as the time of setup and ease of system use for the on-site manager. Due to the short demonstration period, no statistical significance conclusions were drawn from the usability analysis. A subjective ranking of the systems in terms of usability is concluded in the Data Analysis and Results section.

Research Importance

Traffic congestion leads to waste in terms of fuel, time, and money (Schrank and Lomax, 2007). An estimated 2.9 billion gallons of fuel was wasted in 2005 on traffic congestion and delay in the United States. It is estimated by Texas Transportation Institute (TTI) that approximately half of all traffic congestion is attributed to irregular

delays from events such as vehicle crashes, special events, and construction work zones. Permanent ATISs may not be able to notify drivers of this delay since these systems are in set locations. However, portable ATIS may be able to better address irregular delays better than permanent systems since they can be installed wherever needed. Therefore, it is evident there is great importance in the research of this topic.

Thesis Organization

This thesis is organized into six chapters. The second chapter, Literature Review, will discuss previous research in both portable ATIS and human factors in ATIS. The portable ATIS section will cover the need for portable ATIS, the challenges of portable ATIS deployments, and the benefits of portable ATIS deployments. The human factors section will cover aggressive driving, driver behaviors, the connection between human factors and ATIS, and experimental testing.

The third chapter, Study Sites and Data Collection, will first discuss the study site in terms of location and the selection process. This chapter will then discuss the data collection methodology followed by a description of each of the four portable ATISs and the baseline methods.

The fourth chapter, Data Analysis and Results, will first discuss the analysis methodology. This includes a definition of the analysis characteristics and the standards used to compare the data. The chapter will then cover the results of the experiment. This will include accuracy statistical analyses, reliability results, usability results, and the motorist reactions. Finally, this chapter will discuss the capture rates of the systems and any limitations or problems experienced.

The fifth chapter, Phase II Experiments, will cover the background, problem statement, research objectives, scope, and experimental designs of next phase of research.

The sixth chapter, Conclusions and Recommendations, will conclude with the thesis conclusions and recommended future work.

CHAPTER 2

LITERATURE REVIEW

This chapter first discusses advanced traveler information systems (ATIS), more specifically, the background of the project, summaries of past portable ATIS deployments, and both the challenges and benefits of portable ATIS deployments. Following, an investigation into human factors and ATIS will be discussed. This section will include research into aggressive driving, driving behaviors, the effects of human factors on ATIS, and experimental testing of the connection between human factors and ATIS.

Advanced Traveler Information Systems (ATIS)

Vehicle travel continues to be the transportation mode choice for the majority of Americans. The constant building and reconstruction of our transportation infrastructure is an enduring struggle as the amount of traffic congestion and delay continues to rise. Schrank and Lomax (2007) describe the annual delay for a peak-hour traveler to be 31 hours in 1995 compared to 38 hours in 2005. Based on fuel wasted during these congestion times, it cost \$570 per peak hour traveler in 1995 and \$710 per peak hour traveler in 2005 (both in 2005 dollars). This relatively small difference explodes as it is multiplied by the estimated tens of millions of registered American drivers. The authors estimate the cost of congestion at 15 billion dollars in 1982 and a staggering 73 billion dollars in 2005 (both in 2005 dollars). These statistics illustrate the enormous impact congestion has on Americans financially.

Since the general problem of traffic congestion has been addressed in terms of magnitude of financial contribution, a more detailed research into the types and causes of congestion was investigated. Cambridge Systematics (2004) investigated the additional suppliers to congestion other than the regular contributors of high traffic demand and roadway capacity. “Non-recurring” congestion accounts for approximately half of the total amount of traffic congestion. This type of congestion is temporary and irregular but can be separated into several different events. The main events that cause non-recurring congestion include traffic collisions, vehicle breakdowns, special events, roadway construction work zones, and weather related events. Moreover, construction work zones and traffic collisions account for nearly 35 percent of non-recurring congestion. These varying and unsystematic locations for non-recurring congestion point towards the need of a solution in a portable forum.

Currently, many states’ departments of transportation (DOT) encourage traffic management centers (TMC) to implement travel time messages on changeable message signs (CMS). Travel time messages have been proven to reduce driver stress and frustration as the additional traffic information helps drivers plan their routes more accordingly. This will divert a small portion of vehicles to less congested highways. The Federal Highway Administration (FHWA) describes this action as providing critical additional capacity during this time of congestion. In addition to normal traveler benefits, businesses that rely on travel times, such as delivery companies and transit, also greatly benefit with the advanced knowledge as it helps them continue their business trips without lost time.

As this seems like a simple solution to a major traffic problem, usually only permanent or fixed CMS units are available from TMCs. Portable units are almost the only solution to non-recurring delay because of its varying locations and sometimes short (hours) duration. Recently, portable CMS research has begun to increase.

One solution to the portable setting required to solve the non-recurring delay is the implementation of portable ATIS. Portable ATIS has all the added benefits of a traditional fixed ATIS but can be moved to different locations to serve non-recurring events. In terms of work zones, portable ATIS can help inform travelers of an oncoming construction work zone area and the possible delays they might experience. The messages portable changeable messages signs (PCMS) would display can also be used to reduce traveler speeds through work zones. For a shorter congestion period, such as a traffic accident, portable ATIS can be used to divert drivers away from the closed roadway area.

In relation to special events, or other events with a set time period of congestion, portable ATIS can be used to give traveler delays and also additional messages, like parking or exiting directions. In a bigger picture, portable ATIS can be a form of information for TMCs or other traffic operation agencies. Portable ATIS can relate valuable traffic information through PCMSs that may not be initially visible or noticed by TMC personnel.

Challenges of Portable ATIS Deployment

One problem that arises during a portable ATIS deployment or installation is the reliability of the systems. The reliability problem could be in many different shapes and

forms. Fontaine (2003) describes this problem as incorrect system configuration, communication and/or power failure, inaccuracy of the system, or inaccurate posting of traffic information. In this research, six states' evaluation summaries were investigated (Maryland, Iowa, Kentucky, Nebraska, Illinois, and Ohio) using different ATIS prototypes. To be a completely sustainable portable system, none of these listed reliability problems can occur. If a single reliability problem occurred, the ATISs would provide inaccurate information or none at all. Portable systems may not be located near maintenance personnel.

The problem of finding a reliable system is critical to ensuring the benefits of portable ATIS are realized. If a portable ATIS experiences communication or power failure it will not be able to connect to a TMC to provide traffic information. Therefore, the TMC personnel cannot relay this information to PCMS to inform drivers. Reliability often varies system to system with each vendor having a different performance level. One system, Adaptir, uses Doppler radar and was found to have minimal calibration problems as described by Lachhwani and Horowitz (2005). Adaptir is one system that will be later investigated in the report with system deployment. Advances in technology have proven the reliability in portable ATISs is on the rise; however, deployment evaluations are always beneficial in determining the most efficient system at a specific site location.

Benefits of Portable ATIS Deployment

There are several different benefits of portable ATIS. One type of benefit of the upmost importance for construction workers is safety benefits. In regards to work zones,

portable ATIS has the potential to lower the number and severity of vehicle crashes based on increased driver awareness. However, limited number of deployments of portable ATIS in work zones has created an inadequate reliability result. Chu et al. (2005) describe the CHIPS (Computerized Highway Information Processing System) deployment in California that analyzed a work zone before and after portable ATIS deployment. Results show that the amount of vehicle crashes was reduced after the deployment; however, the minimal number of data points created a statistically insignificant result.

In addition to reduction of crashes, reduced traveler speed is another measure of safety in work zones. Portable ATIS has been proven to have the capacity to reduce vehicle speeds through work zones. The SRF Consulting Group (1997) confirmed this result with a deployment of the Smart Work Zone system, a specific portable ATIS. Their conclusions showed a nine mile per hour reduction in their Minnesota work zone evaluation. Additional studies and rationale of speed reduction with implementation of portable ATIS can be found in the latter half of this chapter, Human Factors in ATIS.

Another type of benefit that is evident with the deployment of portable ATIS is operational benefits. As non-recurring delay may spark the use of portable ATIS, it also greatly limits a network's capacity. Advanced traveler information prior to a traffic accident, or other non-recurring congestion events, can help drivers change their route to their destination. This action greatly decreases the traffic demand in the area of the event and increases traffic operations. System setup is important in this benefit as the traffic information needs to be provided to drivers with ample time to change their route. There is conflicting research about the measured amount of traffic that is diverted from the

original roadway section. Fontaine and Edara (2007) found that this value generally ranges from four to twenty percent. Drakopoulos et al. (2001) found a maximum of ten percent diversion in their Wisconsin research. The previously noted Adaptir system was found to divert three percent of traffic in a Nebraska study by McCoy (2000). Although the studies have varying diversion rates, it is clear portable ATIS can be effective in diverting traffic to increase operational benefits.

Khattak et al. (1993) related four issues that should be addressed in route diversion from ATIS studies. First, will drivers rely on the ATIS information and divert their route and what information should be provided? At what level should travel time information be provided and what differentiates diverting drivers? The study further investigated the forty percent of surveyed diverting drivers. They found that of the 73 percent of diverting drivers that normally drive limited access highways, nearly 60 percent of them diverted to arterial streets. This relates a drop in classification in the selected route for drivers. The study also describes diverting drivers will rarely choose an unfamiliar alternative route.

Khattak et al. (1994) furthers his original study by describing previous diversion behavior studies as insightful, but states the need for studies that can quantify the effect of diversion behavior. The research report shows the percentage of diverting drivers can be measured by qualitative, quantitative, and prescriptive information the ATIS device provides. This study begins to draw a connection between the output information provided to the quantity of ATIS benefits.

Through the previously discussed research, portable ATIS has proven to be an effective technology to increase safety and operations at event locations where non-

recurring delay occurs. The challenges in portable ATIS deployment may be resolved with additional deployment evaluations. The following section will discuss human factors in ATIS and further investigate research experiments in safety benefits of ATIS by speed reduction.

Human Factors in Portable ATIS

As discussed previously, ATIS incorporates a great variety of advanced technology to serve the congestion problems in today's transportation infrastructure. Many researchers have begun to tackle human factors research in portable ATIS. Human factors for this paper is defined in a transportation focus as a driver's perception and reaction to traffic conditions and traffic control. Human factors researchers represent a wide range of backgrounds, from psychology to engineering, and they are starting to create uniformity of research results and methodologies.

Barfield and Mannering (1993) relate the cause of the wide range of researcher backgrounds to the new and rapidly developing behavioral science of human factors research and the limitations of knowledge in human cognitive operations. The lack of a "common forum" has resulted in duplicate research studies and numerous publications on nearly identical research. Barfield and Mannering's work summarizes six papers that focus on the behavior and human factor issues of ATIS. The selected papers describe the limits of drivers' information processing, usability testing of ATISs, methodologies used in correlation with dynamic network modeling and driver behavior, and driver tendencies in a congested metropolitan area. The latter investigated paper begins to describe driver tendencies in terms of driving patterns including aggressive characteristics. The possible

benefits of ATIS implementation are the reduction of driver frustration and aggressive driving tendencies with the relay of traffic information. Further research into the connection between aggressive driving and human factors may help future ATIS deployments maximize the system benefits.

Aggressive Driving

Aggressive driving, which originally seemed to be a subjective driving characteristic, has begun to take on the form of several different definitions. Vanlaar et al. (2008) define aggressive driving as, “encompassing a continuum of behaviors that range from extreme acts to less severe manifestations.” The extreme acts refer to shootings or assaults and the less severe manifestations include roadside arguments, confrontations, and gestures. The broad definition sparked further investigation into other published definitions or characteristics of aggressive driving. The frequent term of *intent* arose from their continued study. Some aggressive driving behaviors, such as street racing, excessive speeding, or speeding through a traffic light may not be intended to harm others.

The authors conducted a public opinion poll of a random sample of Canadian drivers in 2006. Their results tell how prevalent aggressive behaviors are in this sample of drivers. Twelve percent of the sampled drivers admitted to excessively speed in the past year and nine percent admitted to often speeding to approaching intersections in an attempt to bypass a red-light. Dula and Geller (2003) generate a similar definition of aggressive driving as “tailgating, abrupt lane changes, and speeding...” in their review of literature. Six of the 19 articles reviewed by Dula implicitly list speeding as a factor of

aggressive driving. Following the review, the authors propose the following three cases of dangerous driving that are labeled aggressive: “intentional acts of bodily and/or psychological aggression towards other drivers, passengers, and/or pedestrians; negative emotions felt while driving; and risk-taking behaviors.” Driver intent, emotion, and behavior are three characteristics researchers are investigating, generally through driver surveys, to forecast aggressive driving patterns.

Driver Behavior

Driver behavior and driving tendencies can be affiliated to drivers’ specific perceptions and cognition as described by Groeger and Rothengatter (1998). Speed and distance estimation of when a driver will reach an approaching object is described as driver perception. Attention to surrounding and driving characteristics is described as driver cognition. Both of these aspects of driver behavior factor into speed and distance estimation. Therefore, the individual driver behaviors can be used to predict speeding or aggressive driving tendencies.

A contributing factor to driver behavior is a driver’s emotions. Mesken (2002) defines driver emotion as, “a specific mental state that rearranges or drives cognition, perception, and action.” Mesken reviews several past studies of measuring emotion by means of observable variables. The three classes of observable variables are overt behaviors (e.g., voice, face, body), physiology (e.g., heart rate changes), and self-reported variables (e.g., questionnaire/survey results). Although all three categories of emotion measures can be used in studies, it is recommended that simulator or actual driving studies be considered.

Hall (1996) validates the reliability of simulation studies and concludes the advancement of traveler information through ATISs can, “contribute to reductions in roadway congestion” based on decreases in driver aggression. This research summary suggests the connection between human factors and the benefits of ATISs from driving characteristics to driver behaviors and emotions.

Human Factors Connection to ATIS

Since there is a distinct connection between human factors and driving in accordance with an ATIS, specific variables or contributors can be investigated to determine their significance. Dingus et al. (1997) explores the effects of age, system experience, and navigation technique with in-vehicle ATIS. Dingus warns the potential risk of increased crash results if ATIS significantly impedes the driving operation. This interface constraint joins limitation imposed by the environment (e.g., visual), driver population (e.g., age), and system (e.g., project cost) that can reduce the possible benefits of ATIS. The results of Dingus’ study show that older drivers had a more substantial benefit by the implementation of an ATIS. The benefit in this study refers to reductions in lane deviations measured by in-vehicle cameras.

Differences in ATIS types (in-vehicle versus out-of-vehicle) affect the implementation and potential benefits, as described by Dingus and Hulse (1993). In-vehicle ATISs have the greatest human factors connection and therefore constitute the most research in human factors connections. However, out-of-vehicle ATISs also have connections to human factors and design guidelines are set in place to maximize potential benefits.

Campbell et al. (1998) summarize several different categories of guidelines that can be used for both research tests and real-world implementations to maximize the benefits of ATIS. These include display guidelines (message characteristics), control guidelines (control type), and routing and navigation guidelines (information presentation). Proper use of these guidelines will help the efficiency of an ATIS evaluation, development, or design.

Experimental Testing

For the past few years, researchers have begun to test ATIS or similar systems in field evaluations. The purpose of these experimental field evaluations is to assess both the accuracy and precision of the systems, and also to summarize the most effective system or message sequence. The various experiments include evaluating ATIS against traditional signage and other speed reduction elements. Since ATIS can be used in both urban and rural settings, the goals of the experiments vary.

Cruzado and Donnell (2009) evaluated the effectiveness of dynamic speed display signs (DSDS) against no speed treatment. The DSDS is a type of DSRS used to reduce driver speeds by providing individual vehicle speeds. The evaluation took place on rural highways in Pennsylvania in speed limit transition zones. Twelve study sites were used with a similar layout. Figure 1 shows the DSDS used in the experiment.



Figure 1: Cruzado DSDS

The experiments lasted for one week in ten of the twelve sites and for two weeks at the other two sites. The results of Cruzado's experiments were that the DSDSs are effective in reducing speeds on average of six miles-per-hour. However, the speed

reductions witnessed during the experiments faded after the DSDSs were removed.

Future research in lasting effects was recommended.

Fontaine and Carlson (2001) performed a similar evaluation experiment with DSDSs and portable rumble strips in rural work zones. For this experiment, data was collected at four short-term, rural work zones. Prior to the experiment, free-flow vehicle speeds through the work zone were recorded. Results found that the DSDSs were generally more effective than the portable rumble strips in reducing vehicles speeds in the advanced warning area of the work zone. The mean traveling speeds were reduced by a maximum of ten miles-per-hour. The percentage of speeding vehicles was reduced with the two speed control systems compared to traditional construction traffic control.

Work zone safety is an area of concern in terms of drivers complying with posted speed limits. Work zones incorporate a large number of pedestrians (construction workers) in close proximities to the travelled roadways. This situation, with the addition of an excessive number of speeding vehicles, has caused thousands of crashes, including fatalities. Brewer et al. (2006) continues the body of knowledge of work zone safety and the use of DSDSs. This particular study augments the research with the addition of a portable changeable message sign with radar (PCMR) and an orange-border speed limit sign. The PCMR used a common message sequence only triggered by violators (Figure 2). PCMR is a subset of DSDS, as PCMR can have additional messages posted while a DSDS can only have the vehicle speed posted. Field testing followed a different sequence as of the previous works studied. First, free-flow vehicle speeds were recorded without the installation of any speed reduction techniques for three days. Second, a PCMR was installed at the merge taper in the construction zone. The sign was in place

for approximately a week (adjustment period), and then data was recorded for three days. Third, the PCMR was removed and after data was recorded after a similar adjustment period. Fourth, two PCMRs were installed (at merge taper and near work zone midpoint) and data was collected after the adjustment period. A similar sequence was used for the other systems. Results from the experiment show that the PCMR significantly reduced 85th percentile speeds for both passenger cars (8 miles per hour maximum) and trucks (6 miles per hour maximum) at the two measurement locations. Brewer concludes PCMS have the, “potential for reducing speeds and improving work zone speed limit compliance.”

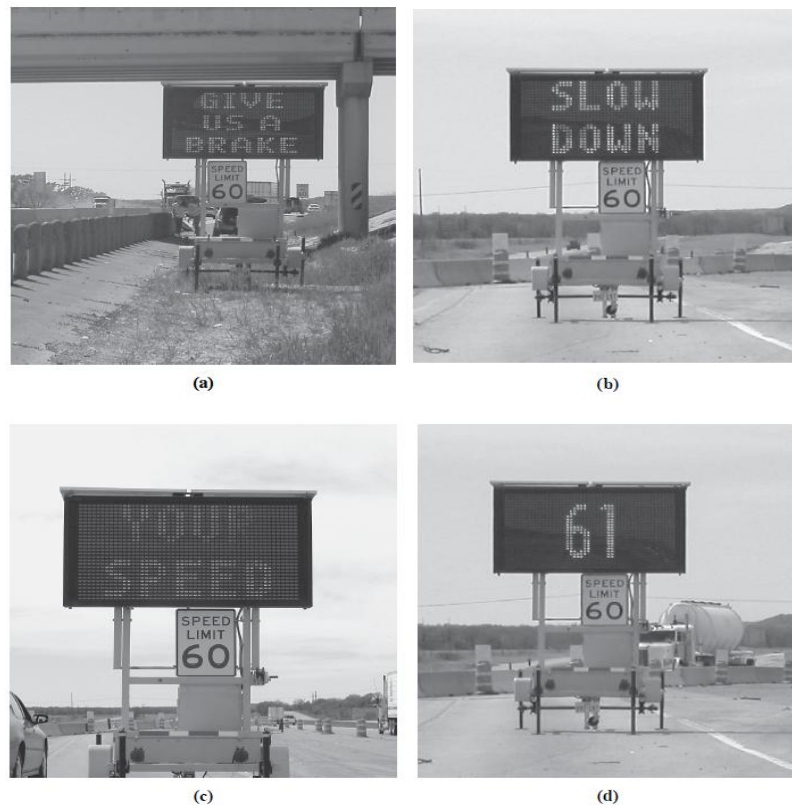


Figure 2: Brewer PCMR Message Sequence:
(a) default, (b) first phase for violators, (c) second phase, and (d) final phase

Wang et al. (2003) continues the research in the strategy of using PCMR for reducing speeds in highway work zones. This study included fluorescent orange sheeting and innovative message signs with PCMRs. The immediate effect and novelty effect were evaluated for this long-term experiment. The PCMR displayed one of two messages: “YOU ARE SPEEDING, SLOW DOWN NOW” for speeding vehicles and “ACTIVE WORKZONE, REDUCE SPEED” at all other times. The experiment lasted three weeks and concluded with significant speed reductions (7 to 8 miles per hour) with the use of PCMRs. The research also found the speed reductions remained reduced and did not return to the original pre-PCMR deployment speeds.

These articles have proven PCMR reduce speeds on rural highways. However, with the varying message sequences these PCMRs use, no conclusion could be drawn on the most efficient (greatest speed reduction) message sequence. Sorrell et al. (2006) focuses an experiment around the speed reductions in work zones based on PCMR message sequences. Four different message sequences were used and are shown in Figure 3. The default sequence was used prior to the cue of the investigated message sequences. Speeds were collected at four different South Carolina work zones during eight days. The four different message sequences were tested independently. All four sequences were shown to decrease speeds with the greatest reduction coming from the first message sequence (11 miles per hour, a few miles per hour higher than the other message sequences). Sorrell’s work is a great example of the research work in human factors and DSRS.

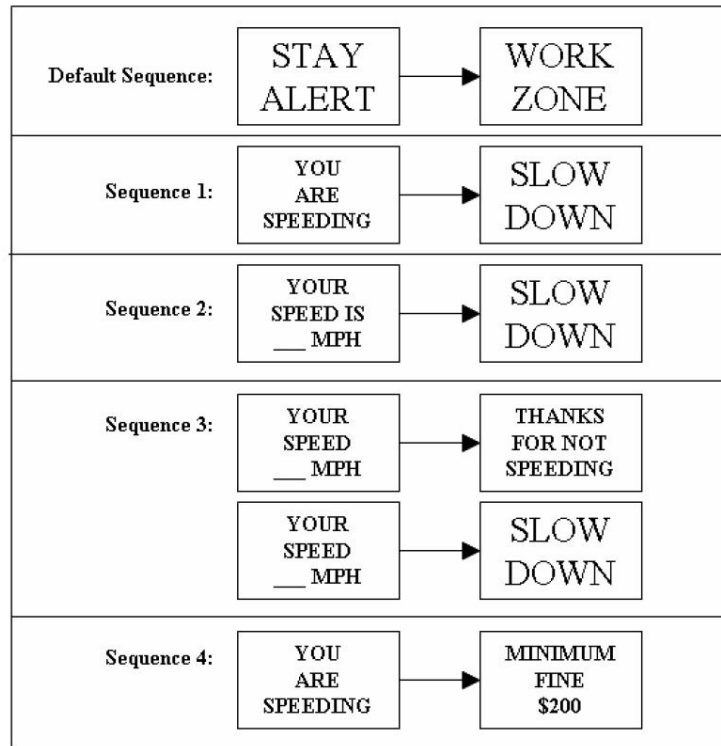


Figure 3: Sorrell PCMR Message Sequences

It is evident from this section of the literature review that there is a connection between human factors and DSRS. Human factors starts being referenced in speed reduction systems and PCMR message sequences in the reviewed literature. Future research, proposed from the literature, recommends the investigation into long-term effects, vehicle type correlations, and PCMR message sequences.

CHAPTER 3

STUDY SITE AND DATA COLLECTION

This chapter will introduce the study site relating it in terms of location and selection. Next, it will include the data collection section. This will cover the data collection methodology and descriptions of the four investigated ATISs. It will also include a description of the baseline measures.

Study Site

The “Dana to Downtown Project” was chosen as the host construction project for the two-week demonstration. The project is located on State Route 44 (SR44) and Interstate 5 in Redding, California, located in Shasta County, which is part of Caltrans District 2. The City of Redding is an urbanized area with approximately 109,000 residents. The purpose of the reconstruction project is to reduce congestion in the greater Redding area, help improve highway traffic safety, and enhance the access across the Sacramento River into downtown Redding. The project entails the construction of an access ramp from Dana Drive to westbound SR44, widening the Sacramento River Bridge from a four-lane to a six-lane facility, and adding off-ramp lanes in the surrounding area. The ground-breaking ceremonies took place on April 22, 2008. Project completion is expected within three years of the April 2008 start date.

During construction, delays are expected to increase as major arterials and intersections will be closed and restricted. The construction project had long been a top priority of the county’s planning committee. Figure 4 shows the highlighted areas of the “Dana to Downtown Project” under construction.

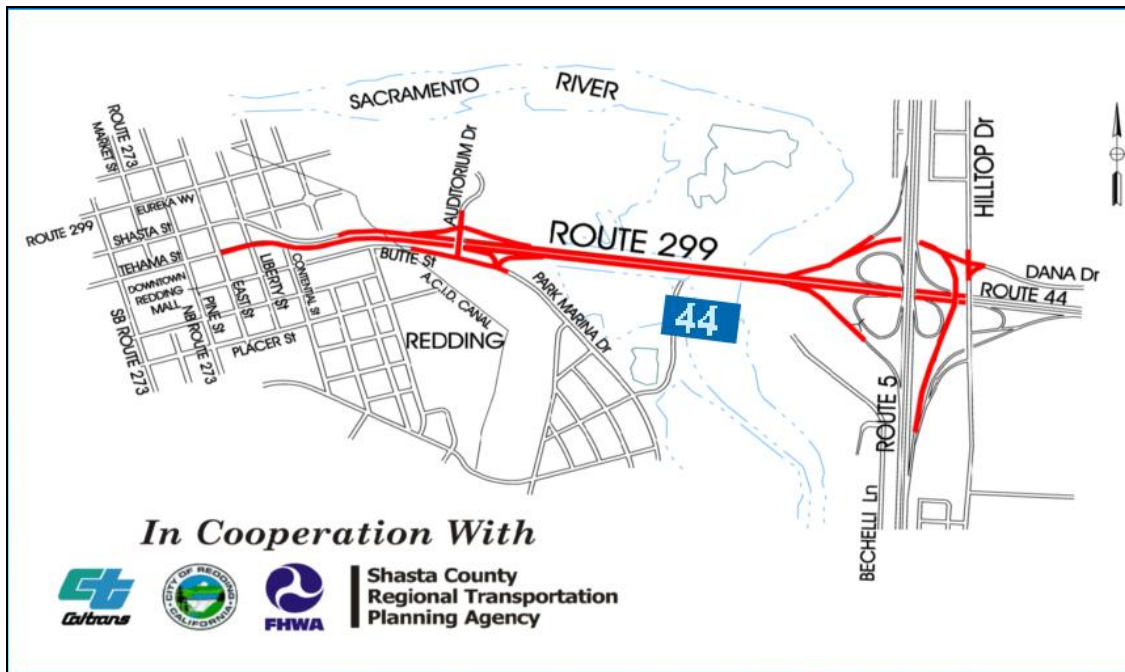


Figure 4: Dana to Downtown Construction Site (Source: Caltrans)

This location was selected by the project manager due to its rural nature in the Caltrans districts. This specific host project was chosen because the bridge is a major connector between the two halves of the city of Redding. The demonstration dates were selected to overlap the Fourth of July weekend, where the greatest volumes of traffic are traditionally witnessed in the area.

Portable ATISs Evaluated

Four portable ATISs were deployed to capture the traffic data throughout the two-week demonstration period: Blufax, iCone, License Plate Reader and Adaptir. The four Blufax units used in the project were leased from Traffax Inc. The Blufax units use a Bluetooth detection system to capture and record Mac IDs from Bluetooth devices in passing vehicles. Each Bluetooth device had its own unique Mac ID. Detectors can be

placed at two or more locations to match up unique Mac IDs and detection times to determine the travel times of the vehicles with the Bluetooth device. The units are battery powered and all data is stored on removable storage cards. The battery life was observed to be approximately eight days and could be recharged in approximately four hours. The units were turned off and removed from their site locations while recharging. For installation, the Blufax units were simply locked to trailers (see Figure 5). Raw Blufax data was recorded with lists of all recorded Mac IDs and detection times. Blustats analysis software was used to post-process the raw Blufax data and generate travel times between locations.

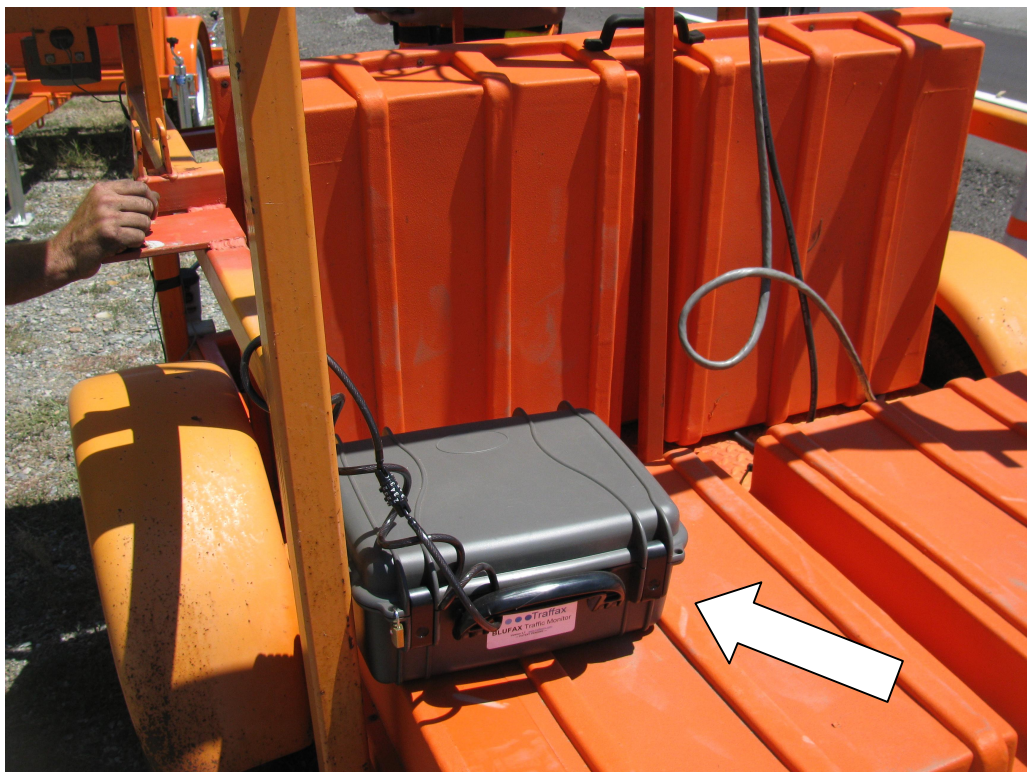


Figure 5: Blufax Unit

Three iCone units, owned by Caltrans, were set up to web interface the status of the iCone units to the iCone Traffic website. Five-minute tabulations of both average

speeds and counts were downloadable from the website. iCones use Doppler radar to measure vehicle speed and satellite communication to upload traffic counts and vehicle speeds to a centralized server. The entire units are encased in a traffic control barrel (see Figure 6). The units were charged overnight off site after approximately a week of continuous collection. For installation, the iCone units are placed close to the highway facing oncoming traffic at about a 45-degree angle. The line-of-sight from the iCone unit to the traffic needs to be clear in order for the iCone to accurately record the traffic data.



Figure 6: iCone Unit

PIPS License Plate Reader (LPR) cameras were provided by the California Center for Innovative Transportation (CCIT). The LPR software uses video images to identify license plate numbers. Similar to Blufax, a unique vehicle can be identified at two

locations in order to determine the travel time between the locations. For this demonstration, license plate numbers and times were recorded and matched up in post processing. These three units were mounted onto portable trailers with the cameras adjusted to point to the closest oncoming lane of traffic. The communication boxes were also stored on the portable trailers. Using the off-line setting, license plate signatures and corresponding recorded times were downloadable from each trailer. Recharging trailers were brought in to recharge the batteries while the system continued to run. Figure 7 is a picture of an on-site LPR unit.



Figure 7: LPR Camera

The Adaptir system included one Remote Traffic Microwave Sensor (RTMS) and two SI-3 radar sensors. The RTMS sensor is mounted onto a portable trailer and is raised approximately 17 feet above the roadway. It records both average speeds and lane-

specific counts every five minutes. The SI-3 radar sensors are mounted on the trailer and pointed towards the oncoming traffic. These sensors record average speeds for every five-second interval. The RTMS sensor and one SI-3 radar sensors were on the same trailer. All the sensors were powered by the batteries on the portable trailer and were recharged by a generator. Figure 8 shows an on-site RTMS sensor mounted on top of the pole. The LPR camera and Blufax unit can also be seen in the same picture. Figure 9 is a picture of an on-site SI-3 radar sensor.



Figure 8: Adaptir RTMS Sensor



Figure 9: Adaptir SI-3 Radar Sensor

Portable ATIS Locations

The installation locations of the systems were determined by the on-site system manager with input from Caltrans staff, the construction manager, and members of the research team. These locations allowed for the analysis of travel times through several routes. The locations were also selected to provide adequate protection from public or construction disturbances. Figure 10 shows the location of the data collection systems and the identification numbers for these systems.



Figure 10: Redding Site Layout

The evaluation focused on westbound traffic across the bridge ending at location 5. Locations 1 through 4 represent the upstream stations for the different routes from which a vehicle can approach the previously described construction site. Location 4 is a single-lane section, and the other locations are two-lane sections. Table 1 describes the route distances and average travel times. The routes in Table 1 are referencing the site locations from previously described Figure 10.

Table 1: Route Data

Route	Travel Distance (Miles)	Average Travel Time (GPS)
No. 1-5	0.9	0:01:48
No. 2-5	1.5	0:02:02
No. 3-5	0.6	0:00:43
No. 4-5	0.55	0:00:46

An on-site system manager was hired from the Scientex Corporation to set up, monitor, repair, and tear down the data collection systems during the two-week demonstration. Scientex utilized the private company of Traffic Solutions to install the systems as Traffic Solutions had trailers and was already managing the traffic control for the construction project. In addition to these daily tasks, the system manager was in charge of recharging all the data collection systems and downloading/delivering the summarized traffic data at the conclusion of the demonstration.

When recharging the portable trailers that power the LPR and Adaptir systems, the on-site system manager coordinated with Traffic Solutions to deliver and remove recharging units to the trailer sites. Traffic Solutions also assisted in delivery of the three iCone units to the Caltrans District 2 equipment garage for recharging. The system manager personally collected and charged the Blufax units.

Data Collection Methodology

Traffic data was collected for the entirety of the two-week demonstration for all four portable ATISs. Any gaps in data collection were a result of system malfunction and were corrected as soon as possible by the system manager. For the travel time systems, LPR and Blufax, individual travel times were recorded from location to location and were limited to the number of passing vehicles and the capture rates. For the spot speed

systems, iCone and Adaptir, average speeds over five and ten-minute periods were generated.

The Adaptir system was the only live system that, through a wireless connection, updated a password-protected website that could be accessed by a laptop computer in the TMC. A TMC representative monitored the laptop for speeds dropping under the desired threshold. For the current experiment, when an average traffic speed over a five-minute period dropped under 35 miles per hour, the TMC representative would post a message on the PCMS. Unless the average travel speeds dropped below the speed threshold for more than five minutes, no messages were posted. The other three data collection systems could measure travel time or speed, but, in their off-the-shelf forms, could not report real-time status to the TMC. These three systems, although not connected to the TMC, were evaluated for their accuracy in measuring travel times, and their reliability (or durability) in a roadside setting. Each data collection system had different traffic information outputs:

- Blufax: Travel times every 15 minutes
- iCone: Average spot speed every 5 minutes
- License Plate Reader: Individual travel times
- Adaptir: Average spot speed every 5 minutes

Systems that measure average speed (iCone and Adaptir) can be used to estimate travel time, assuming the speed is relatively constant between detector stations. If considerable congestion occurred such that speeds varied (or traffic even stopped) between detectors, the travel times may not be accurate.

CHAPTER 4

DATA ANALYSIS AND RESULTS

This chapter first discusses the methodology behind the analysis procedures including the definition of analysis characteristics and the standards used to compare the data. Next, the section will cover the results of the experiment including accuracy and statistical analysis, reliability, capture rates, usability, and motorist reaction. Finally, limitations and problems of the experiment will be discussed.

Analysis Methodology

The purpose of the portable ATIS is to reduce driver frustration, enhance driver safety, and improve traffic operations. Before driver frustration is reduced and driver safety and traffic operations are enhanced, these systems have to prove to be reliable and accurate. For portable ATISs to be selected for use by traffic operations personnel, the systems must prove to be usable or convenient for setup. The portable ATIS was evaluated by analyzing the accuracy of the measured traffic data, the reliability of the systems, the convenience or usability of the systems, and motorist reaction.

System accuracy is directly related to the portable ATIS's ability to estimate delay and/or average travel speed. Using stopwatches and validating with GPS data, travel times were measured manually and credited as accurate real-time data. Each system was compared to this baseline data to test the accuracy. Additionally, travel times and speeds were compared between the portable ATISs. Individual error values (difference of a system to a baseline) were used in analysis rather than average error to portray the percentage of the time the error is greater than the given threshold. This gives a better

indication of how often the system would provide grossly erroneous values to drivers. For example, if half the time the system measured a speed 20 mph above the actual speed and the rest of the time measured a speed 20 mph below, the average error of 0 mph would seem good. Using proportions of individual errors above a threshold (i.e., 10 mph and 10 seconds) would highlight these large errors providing conclusions based on the amount of time the system was noticeably wrong. Another problem with comparing means, or average error, is that small errors that may not be noticeable to drivers could result in statistically significant differences with large sample sizes. Therefore, only proportions of individual error values were used in the accuracy analysis.

Lower bound intervals were calculated at 95 percent confidence levels for the accuracy results. Two separate methods were used in these interval calculations as accuracy results and sample sizes triggered the limitations of both methods. The first method used Bernoulli trials to estimate the lower bounds of the comparisons with sample sizes less than 1000 (e.g., travel time analyses). Raising a proportion less than a value of one to a very large exponent causes rounding problems when calculating the intervals. The Bernoulli trials equation is:

$$f(P|\hat{P}, N) = \frac{P^{N*\hat{P}} * (1 - P)^{N(1-\hat{P})}}{\int_0^1 P^{N*\hat{P}} * (1 - P)^{N(1-\hat{P})} dP} \quad \text{Eq. 3}$$

Where,

P = Proportion of data

N = Sample size

\hat{P} = Measured proportion of data

The Bernoulli trials equation is based on the binomial distribution that the data is either below or above a given threshold of error (mph or seconds). The equation uses an

alpha value of .05. The combination of the binomial probability density function (PDF) and cumulative density function (CDF) normalize the data over the percentage values from zero to one.

The second method used a proportional t-test to estimate the lower bounds of the comparisons with sample sizes greater than 1000 (e.g., spot speed analyses). This method also has its limitations. When the measured value reaches 100 percent, the equation fails (i.e., $P-1=0$) since the denominator becomes a value of zero. In addition, the lower bound will also represent negative values when the sample size becomes very low. The proportional t-test equation is:

$$t = \frac{\tilde{P} - a}{\sqrt{\hat{P}(\hat{P} - 1)/N}} \quad \text{Eq. 4}$$

Where,

\tilde{P} = Measured proportion of data
 a = Attribute of data
 N = Sample Size

The proportional t-test equation is based on the equation provided for testing a population proportion Washington et al. (2003). The proportional t-test equation uses t-value of 1.645 for a 95 percent confidence level (one-tailed t-value used for proportional analysis) on the lower bound.

The reliability of the systems is described based on how each system worked in the field (e.g., failures, maintenance needs, and operational needs). Due to the short demonstration period, no statistical significance conclusions were drawn from the reliability analysis. Observational conclusions in terms of reliability can be found in the Reliability Results section.

The convenience and usability of the portable ATIS was measured based on setup times, ease of system use, and usefulness. Setup times were observed by a student researcher at the beginning of the demonstration. Usefulness was also evaluated by Caltrans staff and the on-site system manager during interviews with these parties. Due to the short demonstration period, no statistical significance conclusions were drawn from the usability analysis. Subjective and observational usability conclusions can be found the Usability Results section.

Accuracy Results

Several travel routes were used to evaluate the accuracy of travel times as measured by the various systems. As shown previously in Figure 10, the routes all end at location 5 and are referred to by their starting location (1 through 4) or by the starting and ending location (e.g., route 2-5). Average speeds collected by the Adaptir and iCone systems are spot speeds investigated at locations 3, 4, and 5.

To provide a baseline travel time, a student researcher drove three selected routes (note, route 4-5 is a subset of both route 1-5 and route 2-5) multiple times per day and recorded stopwatch times at landmarks and equipment trailers along the route. The stopwatch times were synchronized with a portable GPS device to check the accuracy of the recorded times. Stopwatch times with GPS validation are here after referred to as “GPS data” to help readability.

The systems that collect travel times (Blufax and LPR) were compared to the GPS baseline data. These comparisons are limited to the number of recorded GPS travel times, representing a subsample of the data collected automatically by the systems. The

larger samples of the system-measured travel times were compared to each other and the system-measured spot speeds were compared to each other. The systems that collect spot speeds (Adaptir and iCone) were also compared to the GPS baseline data. However, the GPS data provided an average travel speed instead of a spot speed, and thus were not a true baseline. The comparison of system-measured spot speeds between the two systems proved to be more telling, so the GPS-based comparison is not included in this report.

A common way of evaluating the accuracy of detection devices is to report the average error, or the average absolute error. Large positive and large negative errors can cancel each other out showing a system with large errors to have a small average error. Average absolute error provides a better picture, but may not be appropriate for portable ATIS. For example, consider a system that is perfectly accurate 80 percent of the time and has 15 miles-per-hour error 20 percent of the time. The average absolute error is 3 miles-per-hour, which appears acceptable, but the large errors would lead to false alarms or clearly erroneous readings 20 percent of the time (more than twice per hour when considering five minute averages). A more appropriate approach may be to show a cumulative frequency of absolute error. A particular threshold of appropriate error can be applied to the cumulative frequency to determine the percentage of time the system is within this appropriate level of error. Based on discussions with Caltrans staff, error less than 10 miles per hour may be acceptable. Appropriate travel time errors were more difficult to define. For this project, 10 seconds was chosen, somewhat arbitrarily, as a threshold.

GPS Travel Time Comparisons

The LPR camera at location 3 was never functioning properly in the course of this investigation, so the analysis of travel times between the LPR and GPS methodologies was considered over only route 4-5. Multiple LPR route times, beginning within five minutes of the GPS starting times, were used to determine differences in travel times. Therefore, more than one LPR route time could be compared to the same GPS route time. The sample analyzed included 49 LPR travel times and 36 GPS travel times. In an actual portable ATIS deployment, the LPR output would likely be averaged over five minutes (instead of for individual vehicles), which may normalize individual errors resulting in a more accurate estimate. Figure 11 shows the percentage of data points equal to or less than an absolute difference in LPR travel time and the baseline GPS travel time. The maximum error is nearly 16 seconds, which is a large percentage considering the average travel time is 46 seconds along this route. On a more positive note, 98 percent of the readings (91 percent for the lower 95 percent confidence limit) had less than 10 seconds of error.

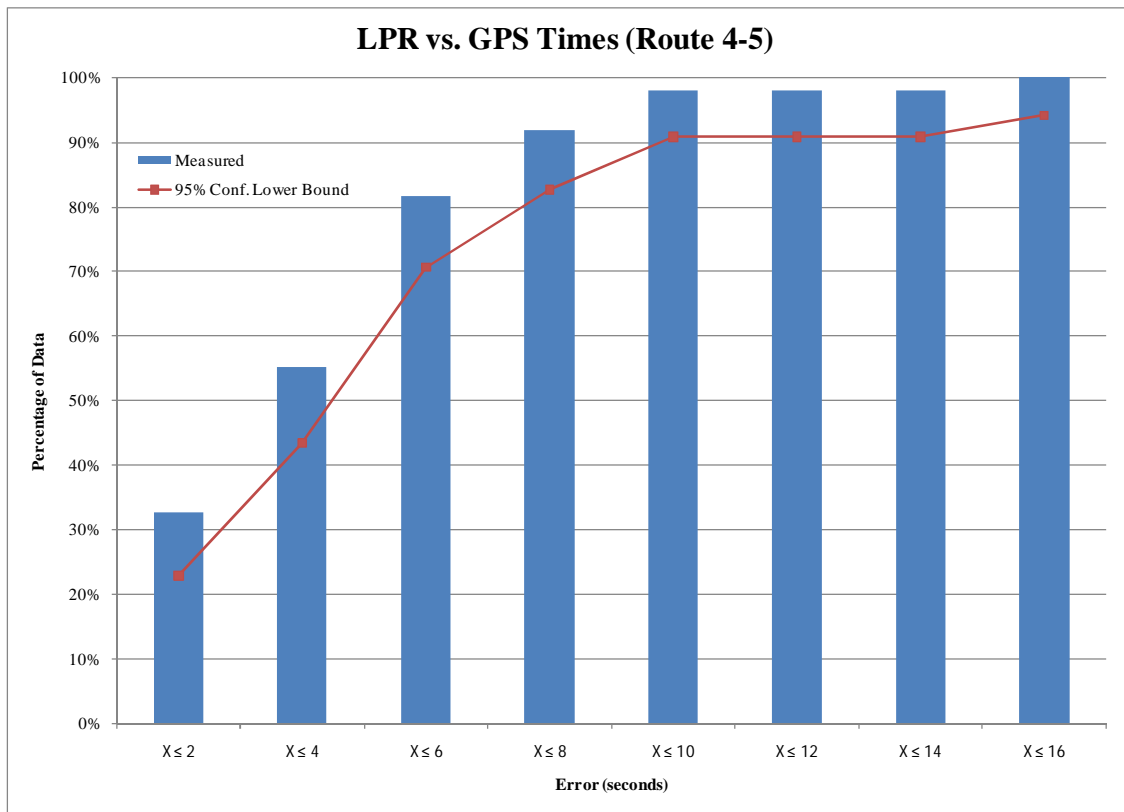


Figure 11: Travel Time Comparison--LPR vs. GPS (Route 4-5)

The analysis of travel times between the Blufax system and the GPS baseline was considered over three routes starting from locations 1, 2, and 3 (all ending at location 5). The Blufax software was limited to outputting 15-minute average route travel times. The 15-minute intervals that included a GPS start time were used to determine the absolute error in travel times. Figure 12 shows the percentage of data points equal to or less than a difference in travel time, or error, measured in seconds for route 1-5 based on a sample size of 11. The travel time averaged 108 seconds along this route. The error was less than 10 seconds only 45.5 percent of the time (25 percent for the lower 95 percent confidence limit).

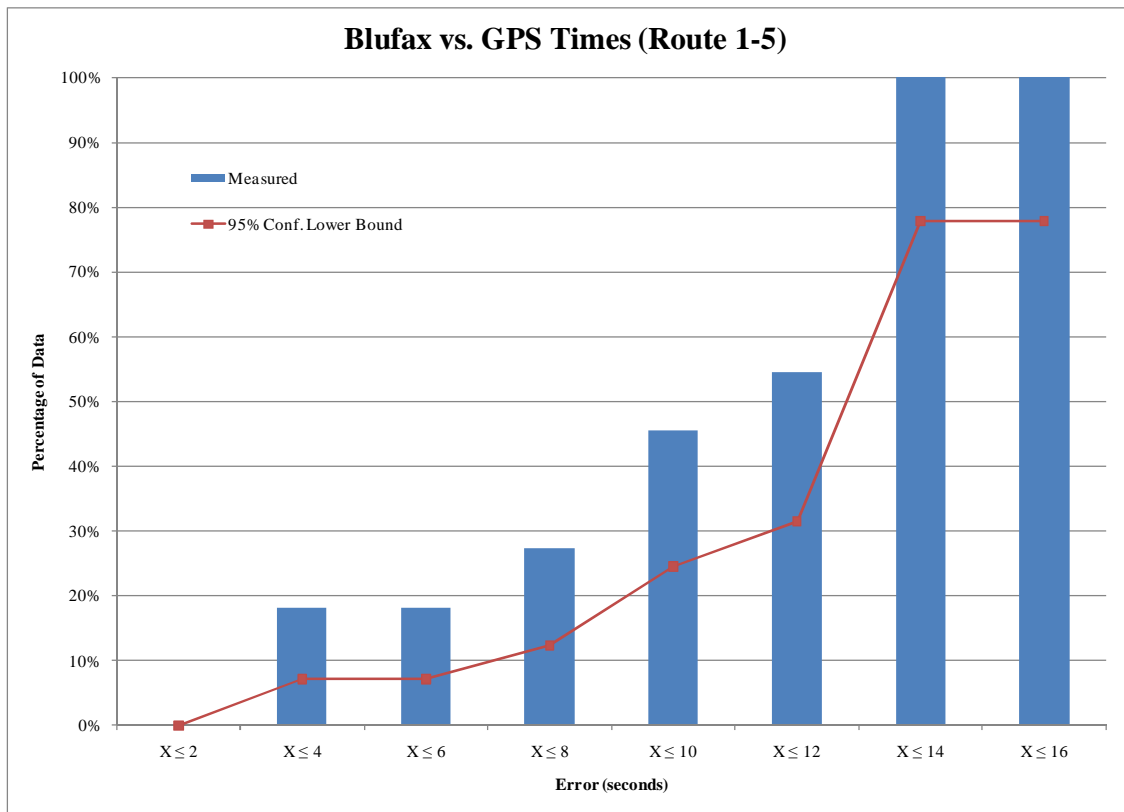


Figure 12: Travel Time Comparison--Blufax vs. GPS (Route 1-5)

Further investigation of the data revealed that the Blufax units on route 1-5 consistently underestimated travel times by an average of nine seconds. This error could be due to a difference in speeds. The Blufax unit at location 1 (see Figure 10) catches southbound traffic on Interstate 5, usually traveling near the posted speed limit of 70 miles per hour. The Blufax unit at location 5 catches westbound Highway 44 traffic, usually traveling less than the posted speed limit of 45 miles per hour. The Blufax units have a detection radius of 300 feet. With the great variance in speed limits for vehicles passing the Blufax units, the exact detection points could vary from hundreds of feet before the units to hundreds of feet after. An average difference in travel times of nine seconds was subtracted from each data point, and a new figure was generated. Figure 13

shows the percentage of data points equal to or less than a difference in travel time or error measured in seconds for the route from location 1 to location 5 after adjustments were made for the nine second shift. This yields much more reasonable results with error within 10 seconds 100 percent of the time (78 percent for the lower 95 percent confidence limit).

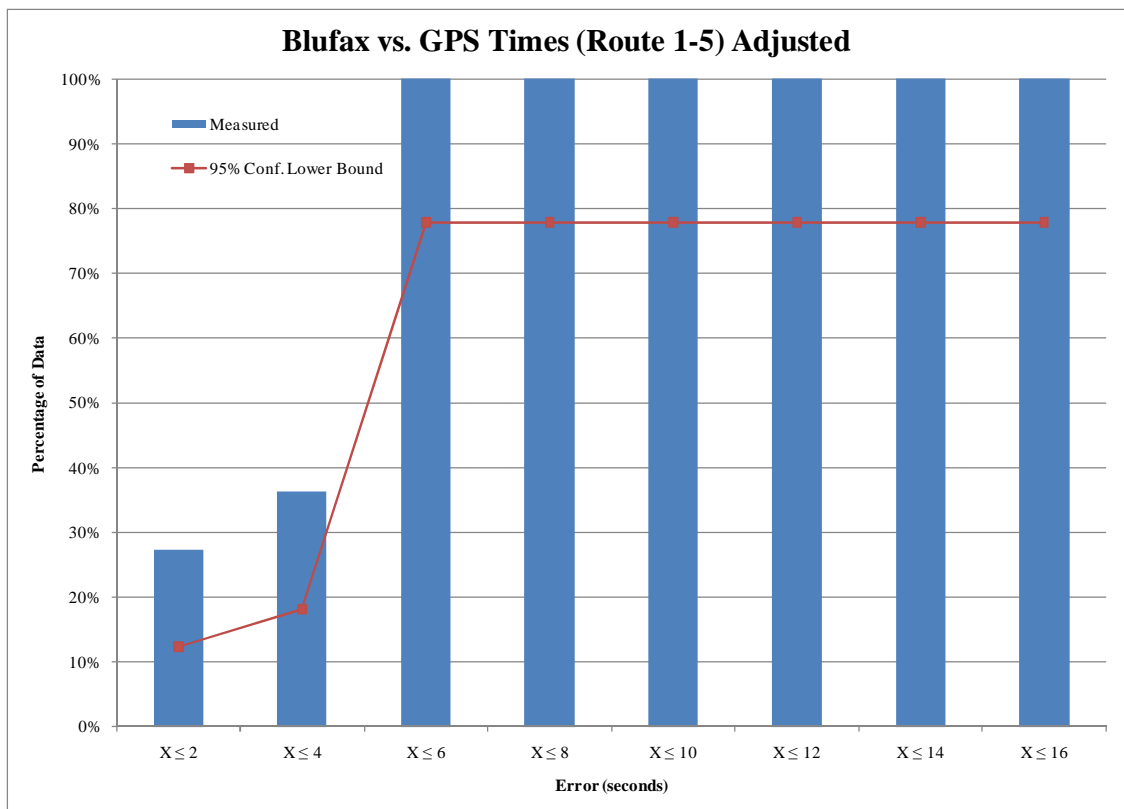


Figure 13: Travel Time Comparison--Blufax vs. GPS (Route 1-5) Adjusted

Figure 14 shows the error in Blufax travel times for route 2-5, and Figure 15 shows route 3-5. These two routes did not show the same systematic error seen in route 1-5, so no adjustment was made. Data for route 2-5 had a sample size of 55 and an average travel time of 122 seconds. Data for route 3-5 had a sample size of 88 and an average travel time of 43 seconds. For both of these routes, the maximum error was less

than eight seconds. Both yield error within 10 seconds 100 percent of the time (95 and 97 percent for the lower 95 percent confidence limits for route 2-5 and route 3-5, respectively).

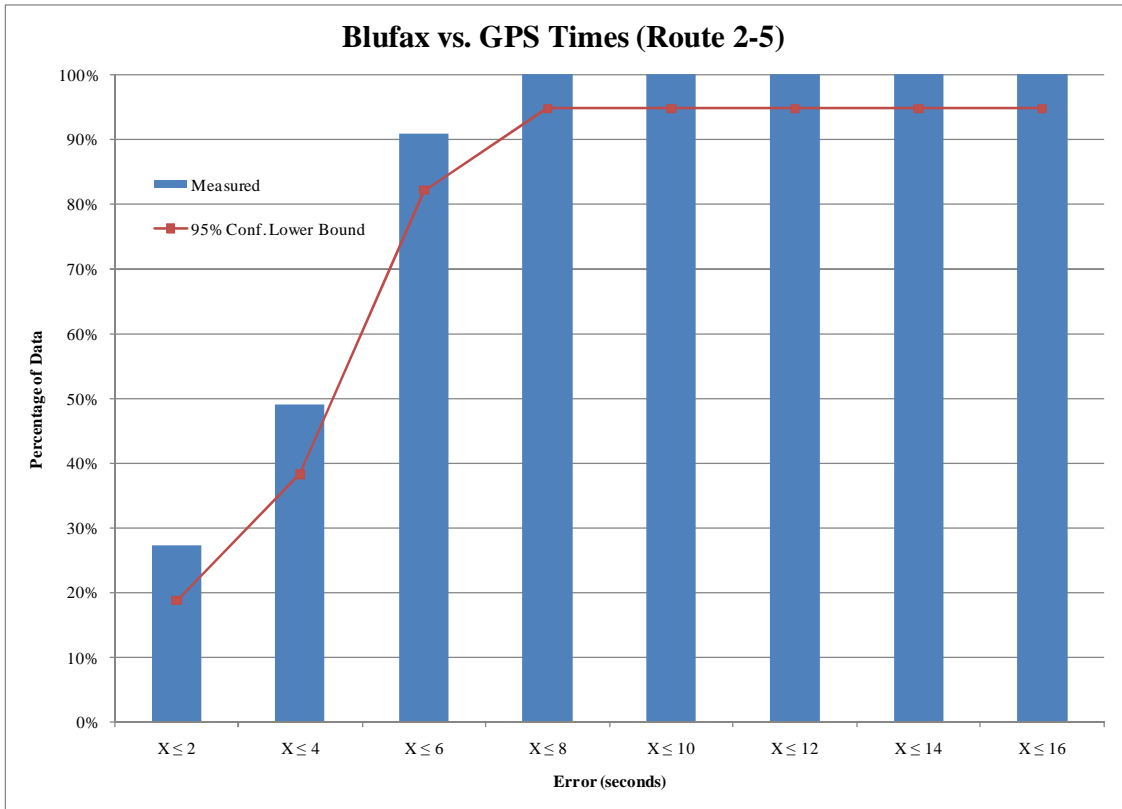


Figure 14: Travel Time Comparison--Blufax vs. GPS (Route 2-5)

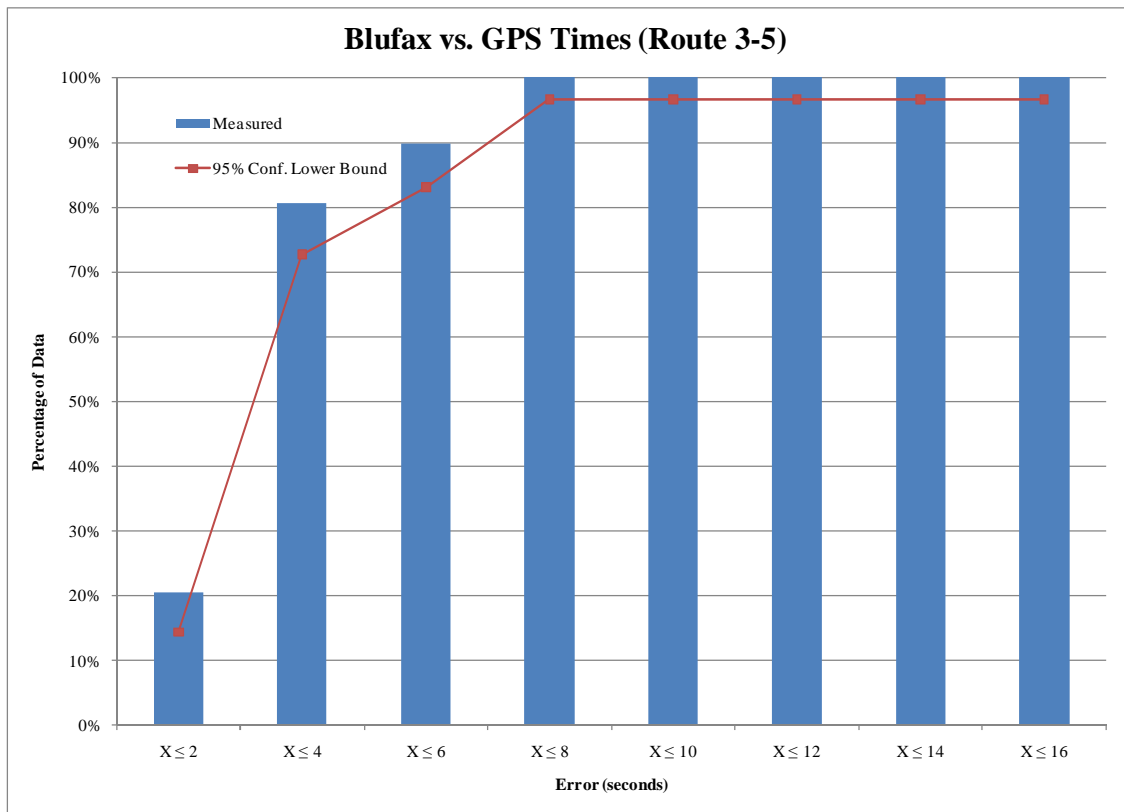


Figure 15: Travel Time Comparison--Blufax vs. GPS (Route 3-5)

After route 1-5 was adjusted, the Blufax system had a maximum error of less than eight seconds for all three sites combined (i.e., 100 percent of the time the error is less than 10 seconds). The problems with route 1-5 indicate the need for validating the system after setup to eliminate systematic errors. The maximum error in travel time for the LPR system was less than 16 seconds. The LPR system had an error of less than 10 seconds 98 percent of the time.

iCone vs. Adaptir Speed Comparison

The analysis of vehicle speed between iCone units and the Adaptir system was considered at locations 3, 4, and 5. Five-minute average speeds for both systems during the entire demonstration were used to determine the difference in recorded speeds.

Figure 16 shows the percentage of data points equal to or less than a difference in speed or error measured in miles per hour at location 3. Figure 17 describes the same comparison at location 4, and Figure 18 for location 5.

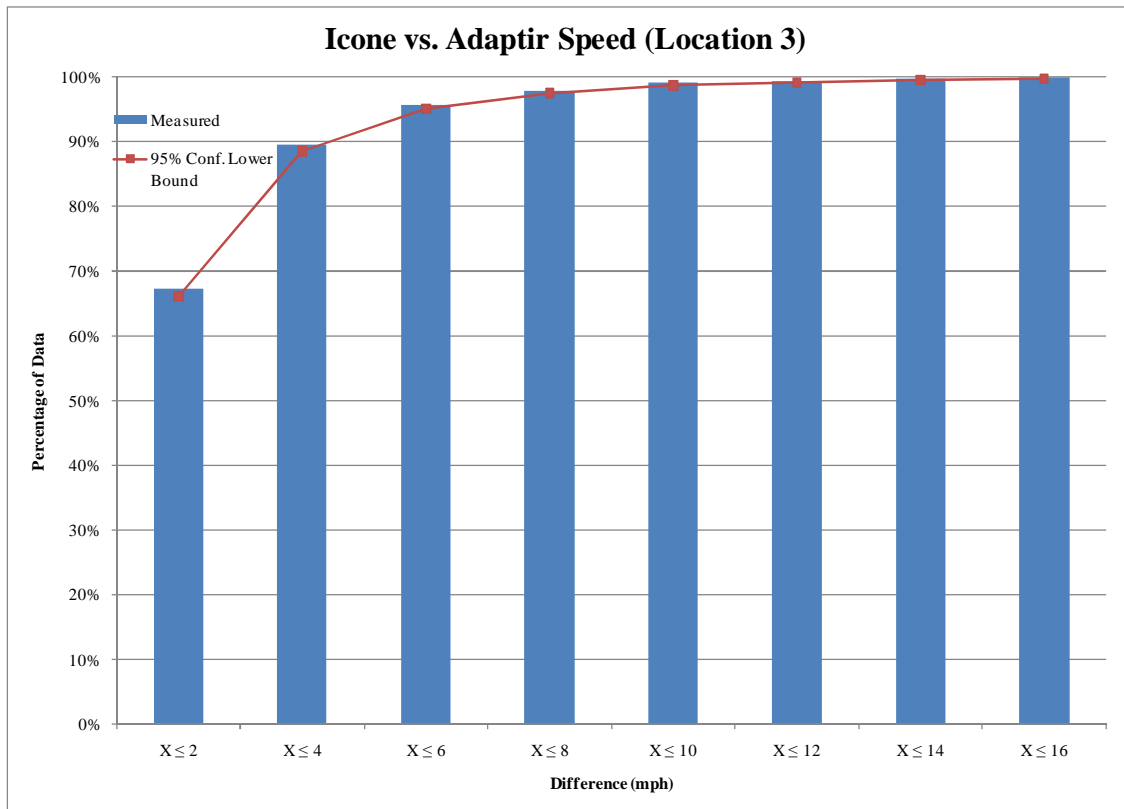


Figure 16: Speed Comparison--iCone vs. Adaptir (No. 3)

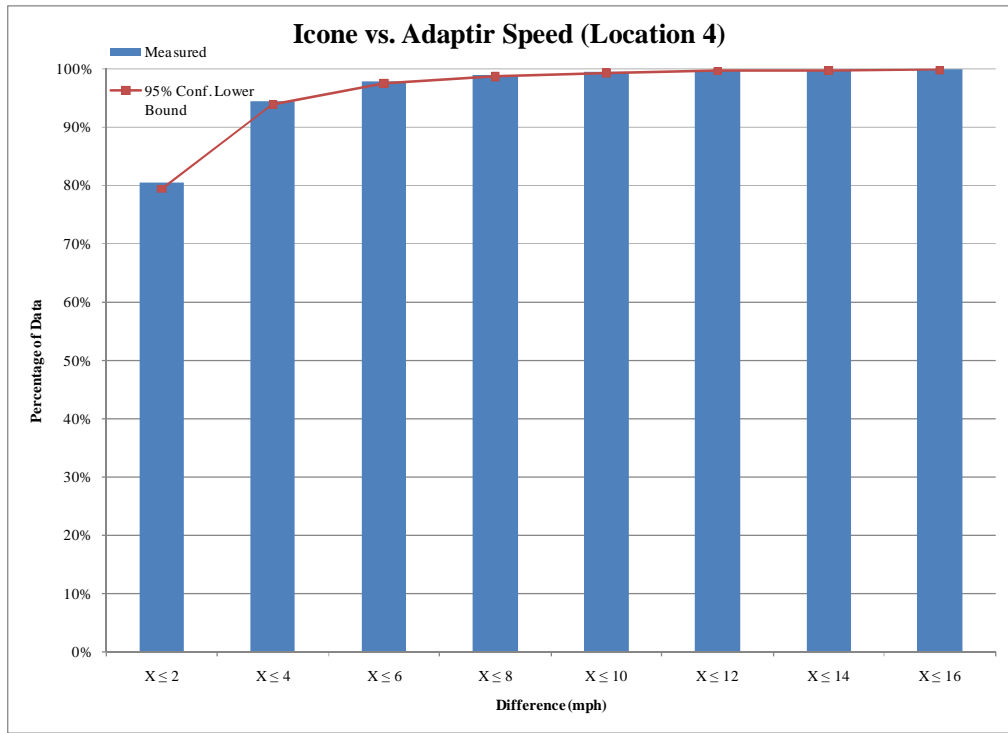


Figure 17: Speed Comparison--iCone vs. Adaptir (No. 4)

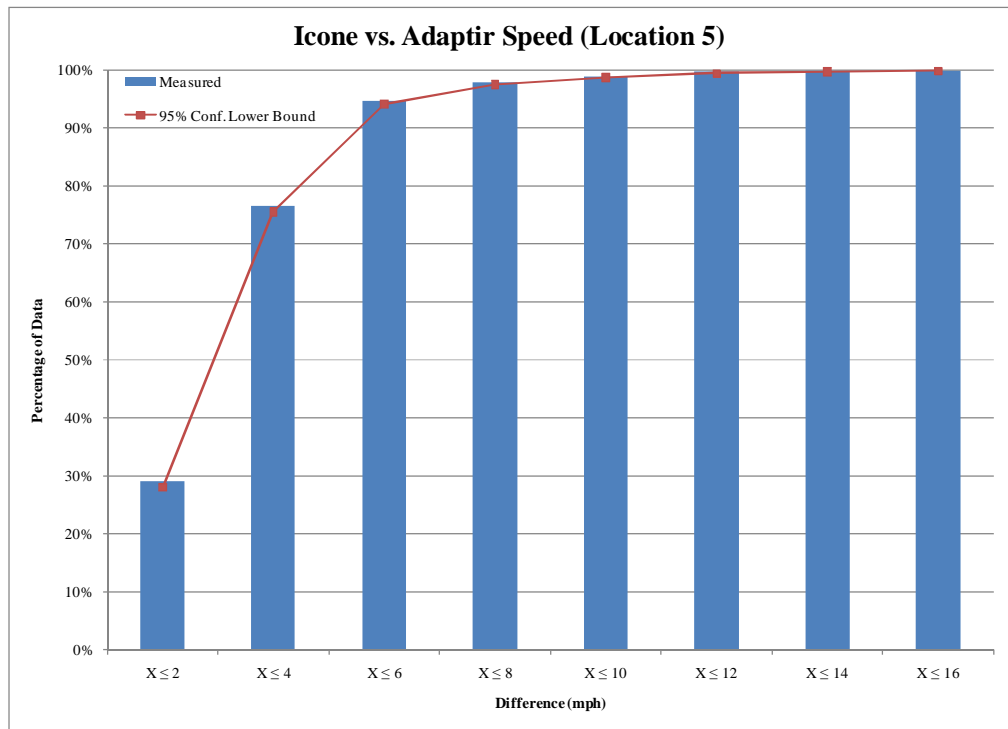


Figure 18: Speed Comparison--iCone vs. Adaptir (No. 5)

These figures are all similar in character, with differences in speeds measured by the two systems being less than 10 mph at least 99 percent of the time and at least 98 percent of the time for the 95 percent confidence lower bound for all locations.

Significance testing was done on the average difference (mph) values for the speed comparisons at all three locations using the paired t-test. All three locations yielded a significant difference in mean difference (mph) values. A summary of the significance testing is shown in Table 2. The average refers to an average difference (Adaptir minus iCone) in spot speeds. The Adaptir speeds are considerably higher than the iCone speeds at location 5.

Table 2: Speed Significance Testing

<i>Spot Speed Investigation- iCone vs. Adaptir</i>			
Significance Testing	Location #3	Location #4	Location #5
Average (MPH)	0.66	-0.77	3.06
Standard Deviation (MPH)	3.02	2.35	2.56
Sample Size	3274	4038	3690
T-value	12.50	20.82	72.61
Table Value ($\alpha=.05$, $DOF>1000$)	1.96	1.96	1.96
Result	Reject H_0	Reject H_0	Reject H_0
H_0 : There is a 0 mph difference between the means of 5-minute average speeds of the two systems at the investigated location			
H_1 : There is a significant difference in the mean 5-minute average speeds of the two systems at the investigated location			

Accuracy Summary

When comparing to GPS data, the travel times were within 10 seconds 98 percent of the time (91 percent for the lower 95 percent confidence limit) for the LPR system and within 10 seconds 100 percent of the time (78 percent for the lower 95 percent confidence limit) if Route 1 to 5 is adjusted. The iCone and Adaptir systems measured

speeds within 10 mph of each other 99 percent of the time (98 percent for the lower 95 percent confidence limit).

Reliability Results

The first step in analyzing the reliability of the systems is to describe how each of the data collection systems worked in the field. This section provides a summary for each system of the types of failures that occurred during the demonstration and what types of maintenance were required.

The Blufax units had very few problems for the duration of the demonstration. The battery life of the Blufax units in the off-line setting was said to be 10-14 days by the manufacturer; however, it was observed that the units lasted between eight and nine days before they had to be recharged. The off-line setup made it difficult to observe a power failure, since the remaining charge available in the batteries was not known until the units were removed and downloaded.

The iCone units also had very few problems. The only problem observed during the demonstration was on July 1, 2009 at approximately 1:00 p.m.; one iCone unit was mistaken for a regular construction cone, and it was turned off and moved by a construction worker. The problem was fixed by the on-site system manager approximately 21 hours later. This problem could have been recognized and fixed sooner by closer evaluation of the online status of the iCone unit.

The LPR system had several problems during the demonstration. The first problem involved the camera at site 3. During installation, the camera would not work. After a couple hours of switching cables and cameras around, it was determined the cable

used at location 3 was faulty and, therefore, no LPR data was collected at location 3 for the entirety of the demonstration. The camera at location 2 had adjustment issues (i.e., was not properly positioned to capture license plate information) near the beginning of the demonstration, which resulted in nearly seven hours of no data being collected. The battery trailer used at this location also caused numerous power failures for the LPR unit resulting in periods of no data. The LPR camera at location 5 also had problems. This unit seemed to react to the high temperatures and the LPR communication box shut off in the afternoons of five consecutive days. The high temperature for these days averaged over 100 degrees Fahrenheit and the system would shut down during the hottest part of the day (12pm to 1pm). In general, the LPR cameras caused the on-site system manager the most frustration and needed the most maintenance of all the systems.

The Adaptir system (including RTMS and radar units) had no problems during the demonstration. There were no gaps in data for the two-week observation period.

The time between off-line settings for the four systems is a unit of measure that depicts the reliability of the systems. For this specific report, Mean Time To Offline (MTTO) is used to describe the average time in days until an offline setting was witnessed for a system during the showcase similar to a Mean Time Between Failure (MTBF) statistic. The MTTO values were calculated by averaging all the portable ATISs' unit values for each system as shown in Table 3.

Table 3: MTTO Values

Mean Time To Offline (Days)			
ATIS System	Battery Related	Non-Battery	Everything
Adaptir	>14 ¹	>14 ¹	>14 ¹
Blufax	8.54	>14 ²	8.54
iCone	7.10	10.18	5.69
LPR	7.24 ³	0.88	0.86

¹ Adaptir systems did not witness any offline times during the showcase, 14 is the number of continuous days the system was online and should be treated as a minimum value

² Blufax systems did not witness any 'non-battery' related offline times during the showcase, 14 is the number of continuous days the system was online and should be treated as a minimum value

³ One or more of the investigated systems did not witness any related offline times so the total days online (14) was used to calculate the MTTO values and should be treated as minimum values

Battery related MTTO values include both recharging efforts and malfunction failures in the calculations. Non-battery related MTTO values include any off-line setting caused by system problems or relocation of systems. Everything related MTTO values include any off-line setting caused by the battery recharging or malfunction, system problems, or relocation of systems. For example, the iCone system experienced a battery failure on average every 7.1 days. All non-battery related issues resulted in the system becoming offline every 10.18 days. Combining these two issues, the iCone would become offline every 5.69 days due to either batteries or some other issue. As shown in Table 3, the Adaptir system has the highest MTTO value since the data collection was not interrupted during the showcase.

Capture Rates

One problem that arose during the demonstration with the Blufax and LPR systems was the lack of data points collected during periods of low traffic flows. With low traffic flows there were periods of time when these systems were not able to report

travel times because there were not enough cars passing that offered the characteristics necessary to be captured by the systems (cars with Bluetooth, for instance). Even though the systems were functioning, Blufax typically had seventeen 15-minute periods per day with no travel times with one consecutive time period of over five hours without a recorded travel time. LPR, when the system was functioning, went as long as 130 minutes without recording an individual travel time.

The Blufax system's capture rate was also restricted by the number of vehicles with a Bluetooth signal present. The Blufax units have a detection zone of approximately 300 feet and could, therefore, record multiple lanes of traffic. On the other hand, the LPR system's capture rate was restricted to vehicles with California registered license plates, and could only record the closest lane of traffic.

Since the LPR system only captured vehicle license plates in the outside lane, the capture rate for the inside lane for two-lane sections was zero. Upon review of the data, iCone appeared to miss many of the vehicles in the inside lane as well.

To further investigate this issue, capture rates for the four data collection systems were calculated for a 22-hour time period when all systems were functioning from July 2nd at 2 p.m. until July 3rd at 12 p.m. The RTMS unit at location 3 was assumed to have the true traffic count values at that location, a section with two-lanes in one direction. The iCone and Blufax data were compared to this RTMS to determine an estimated capture rate for a two-lane location. Because LPR only captures one lane, its capture rate in a two-lane setting depends on how the traffic is split between the two lanes. The iCone unit at location 4 was assumed to have the true traffic count values for a single-lane location. Since Blufax is lane independent, capture rates for one lane should be the same

as capture rates for two lanes. Table 4 shows the capture rates of total vehicles at a single location for the four data collection systems. For the travel time systems (Blufax and LPR), the same vehicle must be captured at two locations to obtain a valid travel time. The rate of a valid travel time from vehicles being captured and matched between two locations is also shown in Table 4. For the match rate percentages, the traffic volume at the first location was used as the total traffic volume used in calculating the match percentages. Traffax Inc. staff suggested a higher capture rate for the Blufax system could be achieved by raising the units higher (e.g., mounting on a pole as opposed to the bottom of a trailer).

Table 4: Capture Rates

Capture Rates of Total Vehicles			
System	Location	Capture Rate	Match Rate
		1 Location	2 Locations
Adaptir RTMS (2 lanes)	3	*100%	
iCone (2 lanes)	3	55%	
Blufax (2 lanes)	3	20%	8%
iCone (1 lane)	4	*100%	
LPR (1 lane)	4	18%	2.10%

*assumed value

Note that for the Blufax system, the total capture rate is based on both the proportion of vehicles with a Mac ID and the ability of the system to capture individual Mac IDs. If the proportion of vehicles with a Mac ID increases, the Blufax capture rate will also increase. Based on the capture rate at one location, at least 20 percent of the vehicles for this demonstration had a Bluetooth device.

Usability Results

The convenience and usability of the portable ATIS was measured based on setup times, ease of system use, and usefulness. Setup times were observed by a student researcher at the beginning of the demonstration.

The Blufax system came preassembled and had the least hassle. No maintenance was needed after the initial switch of the power button. Setup time was simply the travel time to the site locations plus approximately 5-10 minutes to lock the system to a secure object and turning on the unit.

The iCone units also came preassembled and offered little trouble. The iCone units weigh 60 pounds each and needed to be loaded onto a truck to be transported to the site locations by at least two people. Once at the site location, the iCone units were turned to face the oncoming traffic at approximately a 45-degree angle and the power switch was turned on.

The LPR cameras took the most time for setup. The cameras needed to be mounted on the trailers so that they were able to easily pick up on license plates in the near lane, the software needed to be calibrated, and the wiring had to be connected to the power source/communication system. This was all done prior to leaving the shop; however, it could have been done in the field and would take an additional 20 minutes. Each trailer took approximately 30 minutes for setup and calibration. An extra two hours was spent troubleshooting the problems with the LPR camera at location 3 before it was determined the cable was faulty.

The speed radars for the Adaptir system were set up and ready on the first day of the demonstration. The timeframe for mounting and connecting the system was approximately 30 minutes per location. The antenna had to be relocated to a higher vantage point on the trailer to ensure the best communication line of sight. This was done prior to the first two trailers leaving the shop and took about 15 minutes. The RTMS radar also had to be relocated to a specific angle and was therefore remounted, which delayed the deployment of that trailer for another day.

Because several systems were attached to individual trailers, total setup time for a location ranged between 10 and 30 minutes, depending on drop-off location accessibility and the preassemble status. The trucks could only hitch up two trailers at a time, so multiple trailers would mean multiple trips or multiple drivers. The positioning of the trailers proved to be the most time consuming due to accessibility. The actual powering-up took less than five minutes, waiting for the indicator lights to verify the system was working and collecting data. Systems without need for the trailers (Blufax, iCone) would have an estimated setup time of less than five minutes, as their systems are essentially self-contained.

In several conversations with the on-site system manager, he stressed the LPR system needed the most maintenance of the four systems. Hours of setup time would have been saved if all the equipment was checked out first to ensure all the cables and cameras were working properly before they were brought to the project site. In addition, the manufacturer of the LPR system has six separate configurations for data collection, and they were not set up for an offline collection. He noted that the other three data collection systems worked well and required little maintenance or troubleshooting time.

In several conversations with a Caltrans District 2 representative, he noted that the Blufax system seemed like the most realistic and reliable system for use in a rural area like District 2. His one concern was regarding the detection rate and how it would be affected by the limited cell coverage in the district. He also noted that an external power source would need to be used to limit the recharging of the units.

Motorist Reaction Results

A motorist survey was conducted to collect information regarding the impacts of portable ATIS on drivers. The survey asked about changes in frustration, driving behavior, and routing. Some demographic data was also collected in the survey. The motorists would only receive information from the system if there was significant delay; if the speed reported by Adaptir over a five-minute period dropped under 35 miles per hour, the TMC representative would post a message on the PCMS. This condition was never met. Because messages were never posted, no response to the system could be measured.

The survey did have a few responders (8 respondents). All the respondents traveled through the construction area and were knowledgeable about the construction before their trip. There was a 50/50 split of respondents who said the construction delay caused them frustration versus those who said it did not cause any frustration. Since the congestion threshold was not met, the changeable message signs were never updated and the remainder of the survey data was insignificant. The survey was advertised several times. A link to the online survey was posted on the Caltrans webpage and a public service announcement was made to notify the public. In addition, business cards with the

survey link were handed out randomly at a visitor center adjacent to the construction site.

A draft of the original survey can be found in Appendix A.

CHAPTER 5

PHASE II EXPERIMENTS

This chapter first discusses the background of the potential future phase of the project including the limitations and problems witnessed in the original experiment. This chapter summarizes the limitations of the study detailed in this thesis. Reasoning for the future experiments is provided in detail in Appendices B and C.

Phase II Experiment

The original portable ATIS deployment demonstration was subject to a wide variety of problems and limitations that hindered the overall effectiveness of the deployment. The problems witnessed included both system problems and design problems. System problems were anything relating to the portable ATIS that malfunctioned or hindered it from collecting data for the entire two-week deployment. The most common system problem was overheating of the systems. The high temperatures of the days of the demonstration exceeded 100 degrees Fahrenheit. These problems included complete system shutoffs and system adjustments. Resolving the system problems may involve additional research into the capabilities of the systems under extreme weather conditions. Altering the locations of the equipment could also be a possible solution to this specific type of problem.

Another type of problem witnessed during the deployment was planning problems. These problems were results of the original project planning. They included a limited number of travel time and spot speed comparisons, malfunctions of systems because of construction worker movement, loss of data collection because of faulty

equipment, loss of data collection and comparisons because of scattered recharging times, and no baseline to use for speed studies. The Phase II experiment, detailed in Appendix B, will repeat the evaluation of accuracy attempting to avoid the challenges encountered in the original study.

Headways Experiment

No studies were found that demonstrate PCMS messages reducing driver frustration and aggression. The headway experiment will begin the research of using PCMS messages to reduce driver frustration (e.g., tailgating) and can be found in Appendix C.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter discusses the major findings of the research presented in this thesis. It also proposes future research recommendations for portable ATIS and human factors.

Conclusions

Portable ATIS has the potential to provide real-time traffic information—including advanced travel times, delay times, and reduced average speeds—to motorists by updating PCMS with real-time messages. Advance notice of traffic flow changes can help alert drivers to use alternate routes, drive more safely, and make informed travel decisions. However, there is currently a lack of implementation of portable ATIS because of a limited number of demonstrations.

Caltrans initiated this research project to further investigate portable ATIS. The project has reviewed existing best practices, interviewed practitioners, and identified and reviewed off-the-shelf technology, as summarized in the Concept of Operations Report (CCIT 2009). This report summarizes the demonstration effort where four systems (Blufax, iCone, License Plate Reader and Adaptir) were deployed to for a two-week period. Table 5 summarizes the results of the demonstration.

Table 5: Summary of Results

System	Measures	Accuracy (% \leq threshold)*	Reliability**	Usability***	Integrated System
Adaptir	Speed	99/95/97	M, B	Medium	Yes
iCone	Speed	99/95/97	M, B	Easy	Partial
Blufax	Travel time	78/99/99	B, C	Easy	No
LPR	Travel time	91	M, B, O, C	Hard	No

*Accuracy percentages for the same system using different travel routes or locations are separated by slashes. The threshold for speed analyses is 10 mph and 10 sec for travel time analyses.

**Reliability challenges included: M- a unit was accidentally moved by construction workers, B- the units required a recharge of the batter, O- the unit shut down apparently due to overheating, C- during low traffic the system went periods without reporting a travel time due to the capture rate.

***Note the usability categorization is based on the authors' opinions and may be somewhat subjective. For more detail on the specific usability issues, refer to the body of this report.

Two of the systems measure spot speeds and two measure travel times. Travel times could be estimated from spot speeds. The accuracy of these estimates would depend on the variability of speeds between detectors.

In general, all the systems were found to record fairly accurate traffic characteristics based on the threshold values used in accuracy analyses. The systems were almost always accurate within 10 miles per hour spot speed or 10 seconds travel time with the exception of Route 1-5 as measured by the Blufax system, though its errors could have been fixed by validating the travel time. Since not 100 percent of the errors in travel times and spot speeds were not less than or equal to the 10 seconds or miles per hour thresholds, the null hypothesis is rejected and the alternative hypothesis is accepted.

The very nature of a portable system requires that the systems run on batteries. The batteries on all the systems needed to be recharged at least once during the demonstration project. This problem could be remedied for any of the systems with more solar panels and batteries. Some of the systems were moved by construction staff as they were mistaken for traffic control devices. The LPR system had the most reliability issues with several shut downs that were assumed to be due to overheating. Both of the travel

time systems had challenges estimating travel times during low traffic periods as they only captured travel times for a portion of the vehicles (two percent for LPR and eight percent for Blufax).

The ease of installation and usability could be improved for some of the systems. The Blufax and iCone systems are simply set in place and switched on. The LPR system requires alignment of the cameras and calibration of the software. The Adaptir system requires alignment of the radar units and the RTMS unit. Although it was the only fully integrated system, Adaptir also required ensuring the antennae had line of sight between the trailers.

Of the four systems Adaptir is the only system integrated with communications and software to allow for real-time updates to the TMC. The Adaptir system could have also been configured to update the PCMS directly. The iCone system does have a communication component to allow for storage of the recorded traffic data to a central server, but would take some work to provide real-time warnings to the traffic management center or to automatically update PCMS. The LPR and Blufax systems, as provided, were not integrated into a deployable system and were evaluated with post-processing of the data collected. However, these two systems could be integrated into a similar deployable configuration with real-time updates to the TMC.

Recommendations

Further demonstration of portable ATIS should be done incorporating a longer testing period, a site with no cellular phone service, and including systems that have integrated control and communication capabilities so they are ready to use. Future

demonstrations should be conducted on sites that have a high likelihood of experiencing delay so motorist responses to the system can be evaluated. It is also recommended that traffic operations personnel be interviewed to determine what an acceptable error threshold is for travel time. In the original experiment, 10 seconds and 10 miles per hour were used as error thresholds.

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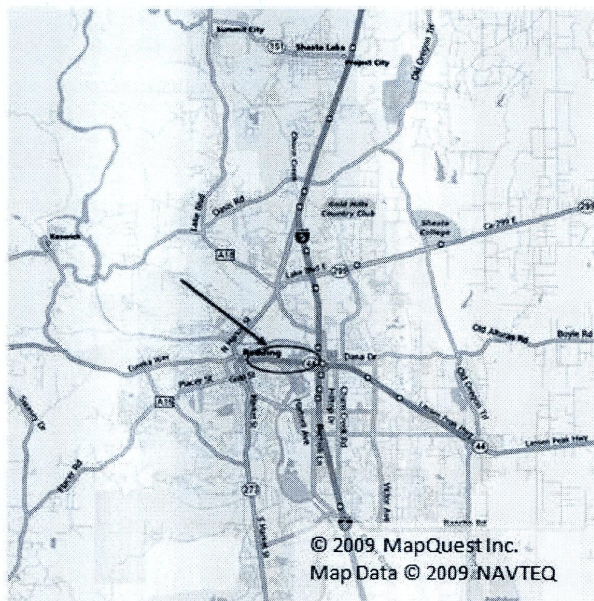
APPENDICES

APPENDIX A

ORIGINAL PORTABLE ATIS DEPLOYMENT MOTORIST SURVEY

The California Center for Innovative Transportation (CCIT) and the Western Transportation Institute (WTI), in cooperation with Caltrans, implemented an experimental system to estimate travel times and delays along State Route 44 through the Dana to Downtown construction project. This system provided motorists with real time delay information. In order to determine the effectiveness of this delay information, CCIT and WTI are conducting a survey of motorists that have driven through the construction site or diverted around construction during the test period.

Your opinion about this system is important in determining the direction for future real time delay information to travelers. Responses will be used for research purposes and are completely confidential. This survey will take approximately five minutes to complete. If you travelled through the construction site, shown on the map below, between Monday June 29 and Monday July 13, or if you wanted to travel through the area under construction during these dates, but did not due to the construction, please proceed with the link below and complete the entire questionnaire.



1. Have you taken this survey before?

- No
 Yes

2. Concerning your auto travel between Monday June 29 and Monday July 13, select which statement is most accurate (if both are true, select the answer for only the most recent trip):

- I traveled through the construction project on State Route 44 near downtown Redding.
 I wanted to travel through this area, but took an alternate route to avoid the construction.

3. Did you re-route to avoid the construction because of the messages displayed on the portable changeable message signs?

- No
 Yes

4. Which direction did you travel through the construction zone?

(Please select only one)

- Westbound
 Both
 Eastbound
 Not sure

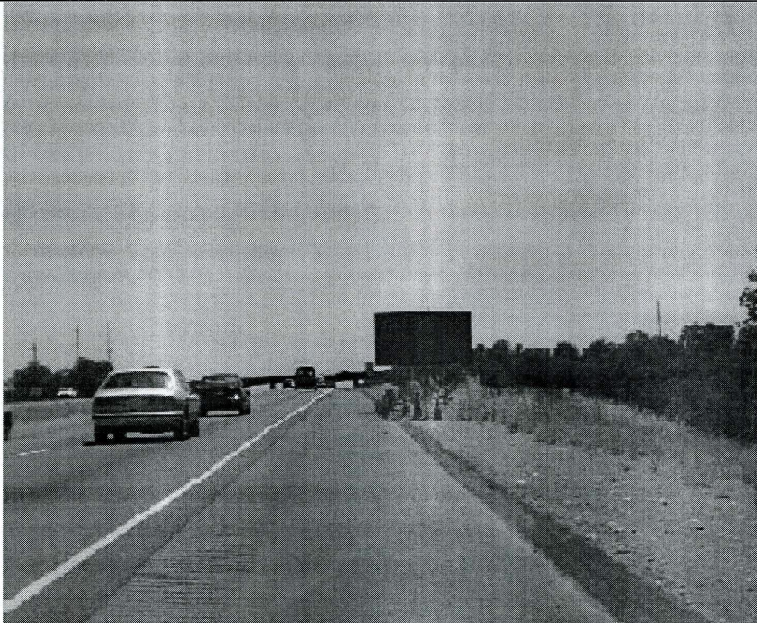
5. In the past three months (i.e., May, June and July 2009), how often have you driven through the construction site?

(Please select only one)

- It was my first time
 Monthly
 Weekly
 Daily

6. Did you notice the portable changeable message signs?

- No
 Yes



7. To the best of your recollection, type the message that you saw on the signs:

- Sign was blank
- Sign had a message (please specify)

8. Did the message on the sign have information about the amount of delay caused by the construction?

- Yes
- No

9. Did the construction delay cause you any frustration?

- The construction delay frustrated me
- The construction delay did not cause me frustration

10. If the construction delay caused you frustration, how much did the delay information on the sign reduce your frustration?

- Very much
- Slightly
- No change
- It increased my frustration

**11. How did information provided on the sign change your driving behavior?
(Please select all that apply)**

- I did not attempt to pass vehicles
- I did not follow vehicles as closely
- I drove slower
- My driving behavior was unchanged

**12. How accurate were the messages provided on the sign?
(Please select only one)**

- The message was accurate
- The message was close to accurate
- The message was wrong

**13. On a scale of 1 to 5, rank the usefulness of the information displayed on the sign?
(Please select only one)**

1. Very Useful
- 2.
3. Somewhat Useful
- 4.
5. Not Useful

14. Were you the:

- Driver
- Passenger

15. How many people were in your vehicle, including yourself?

16. What type of vehicle were you driving?

- Commercial Truck
- Car/Pick-up/Van
- Other (please specify)

17. What is the purpose of your trip?

- Leisure
- Work
- Other (please specify)

**18. Which day did you drive (or want to drive) through the construction site?
(Please select all that apply, including the most recent trip)**

- Monday, June 29
- Tuesday, June 30
- Wednesday, July 1
- Thursday, July 2
- Friday, July 3
- Saturday, July 4
- Sunday, July 5
- Monday, July 6
- Tuesday, July 7
- Wednesday, July 8
- Thursday, July 9
- Friday, July 10
- Saturday, July 11
- Sunday, July 12
- Monday, July 13
- Don't remember

19. For the most recent trip, what time of day did travel (or want to travel) through the construction zone?**20. Did you know about the construction before you started your trip?**

- Yes
- No

**21. Where did you receive information about the status of the construction?
(Please select all that apply)**

By driving through it on previous trips

Internet

Newspaper

Radio public service announcements

Television news

Other (please specify)

**22. Where do you live?
(Please select only one)**

In the greater Redding Area

Within 100 miles of Redding

Greater than 100 miles from Redding, CA resident

Not CA resident

23. Do you have any comments on how to improve traveler information about construction delays?

Your responses are very beneficial in shaping future forms of traveler information. Thank you very much for your time.

APPENDIX B

PHASE II EXPERIMENTAL DESIGN

EVALUATION OF PORTABLE ADVANCED TRAVELER INFORMATION SYSTEMS (ATIS) PHASE II

This phase II experiment is a stand-alone document that will advise a future researcher in executing a second phase of the original portable ATIS deployment. An evaluation of literature in the topic depicts a limited number of studies that accurately evaluate portable ATIS as previously defined. This experiment is intended to evaluate the accuracy of portable ATIS.

Research Methods

The design of the experiment is focused on resolving the limitations that were witnessed in the original deployment evaluation. The research methods section covers the Research Objectives and the Hypothesis Statement of the experiment.

Research Objectives

The objective of this experiment is to develop a more in-depth understanding of the accuracy of ATIS in a portable setting. It is necessary for portable ATIS to provide accurate traffic information before improvements to roadway safety and traffic conditions become evident. Three separate ATISs will be evaluated on their accuracy during a two-week period.

Hypothesis Statements

Previous research indicates different portable ATIS may have different levels of accuracy. ATISs may be unreliable in a portable setting.

Accuracy is important in the systems to increase the driver confidence in the system. If a portable ATIS provides inaccurate traffic information, drivers' frustrations and aggressions may not be lowered but raised. Accuracy is also important to Caltrans or other deploying agencies. The public perception of Caltrans could be jeopardized if they implement an inaccurate portable ATIS. Accuracy is defined as the ability to measure travel times or speeds. Error is defined as the difference of the measured value by portable ATIS and some baseline. For this experiment, individual error will be used for analysis against given thresholds. Using individual error to generate proportions of data against error thresholds, conclusions can be drawn describing the proportions of time the portable ATIS is erroneous. These conclusions will describe the accuracy, or the ability to measure travel times or speeds, of the portable ATISs as defined above. The thresholds of 10 seconds and 10 miles-per-hour will be used in travel time and speed analyses, respectively.

It is believed all three investigated ATISs will be accurate to available baselines in the portable setting for the entirety of the two-week deployment. The null hypothesis for this research is that 100 percent of errors in travel time and spot speed systems' data are less than or equal to 10 seconds and miles-per-hour, respectively. The hypothesis statement is:

$$H_0: P_{10} = 100\% \quad \text{Eq. 1}$$

$$H_1: P_{10} < 100\% \quad \text{Eq. 2}$$

Where,

P_{10} = Proportion of data with error \leq 10 mph or sec

Research Procedure

The research procedure is broken into six sections: Site Location, Investigated ATIS, ATIS Setup, Proposed Analysis, and Conclusions. The Site Location, Investigated ATIS, and ATIS Setup are subject of the author and do not change the scope of the experiment if replaced or altered. The proposed analysis recommends one direction for analysis. The Conclusions section summarizes the proposed experiment.

Site Location

Selection of the site location is critical to the effectiveness of the experiment to generate results. It is recommended that the site location have the following characteristics:

- Rural area without cellular phone coverage
- Minimum of one mile length but preferably approximately five miles
- Congested area (LOS D or lower) or peak hour congestion
- Work zone area

The site should be limited at a two-lane highway for easier data collection. Any additional lanes will lower the chances of constant congestion and could possibly overload some of the equipment. It is also important the construction on the site selected remains in the same area for the duration of the experiment to not introduce an extra factor.

Investigated ATIS

The investigated portable ATISs will be Blufax, iCone, and Adaptir systems. The capabilities of these systems deemed to be sufficient in the original deployment and the results interested the Caltrans staff. The redundant portable ATIS deployment will help validate the initial findings while attributing a more thorough data collection.

The travel time system (Blufax) will be set up to capture individual vehicles as they pass the system. They will be set up in different sequences to provide multiple travel time routes, which are described in more detail in ATIS Setup. The travel time system will be set in an off-line setting to allow the researcher to do a number of different analyses.

The speed systems (iCone and Adaptir) will be set up to capture spot speed averages over five-minute durations. These systems will be set up together at several locations, which are described in more detail in ATIS Setup.

In terms of a baseline, an additional, prior-calibrated, radar speed system will be used to evaluate the two speed systems. Since this system is only being used as a baseline system and not for analysis purposes, the system will only be installed at one location. The baseline system can be installed at all locations if the project budget allows it. A researcher will drive the travel time routes and record several travel times for a baseline for the travel time systems.

For the sample size calculation, it is recommended that 8 seconds be used for the standard deviation based on original travel times collected. It is also recommended that 1.96 (two-tailed analysis) be used for the confidence interval and 2 seconds be used for the accepted range of error. With these values, a minimum sample size of 62 travel times

is required. Man-hours can be calculated after the site selection has been completed and the travel routes are determined.

ATIS Setup

Figure 1 below shows a proposed layout of the ATIS experiment. The layout of the experiment is dependent on the exact site location but it should follow a similar setup.

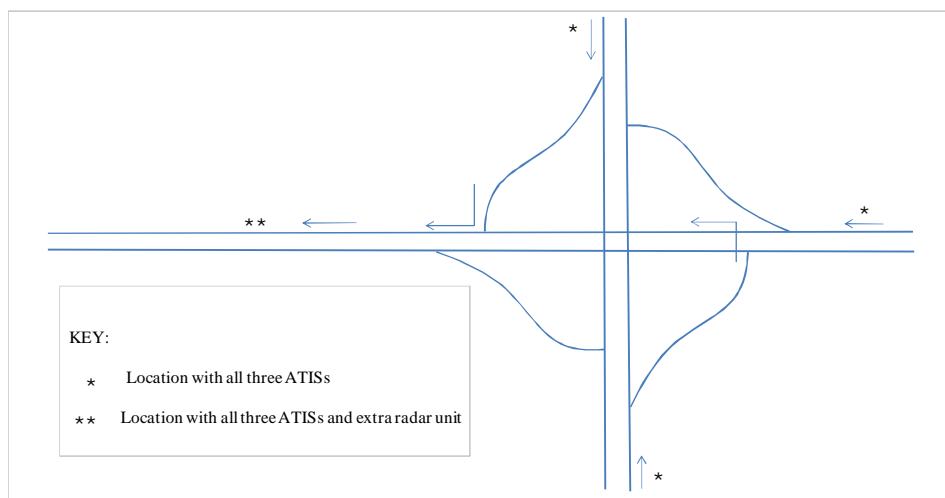


Figure 1: Proposed Site Setup

The systems were placed to allow for maximum overlap of routes and therefore the maximum number of potential analyses.

Proposed Analysis

The systems will be checked and data downloaded at the end of two weeks. This will provide analysis for a short-term deployment. In regards to the baseline, the additional speed radar will be able to collect data for the short-term deployment.

Results should be presented in percentage of data with errors less than the threshold. Error will be in units of seconds for travel time systems and miles-per-hour for spot speed systems. Lower limit confidence bounds should be calculated and presented

in results using the proportion t-test at a 95 percent confidence interval. Finally, significance testing may be done between each individual system and the corresponding baseline. The paired t-test with an alpha value equal to .05 and the degrees of freedom equal to the sample size minus one should be used for the significance testing. The results of these tests should determine if the means of the groups are significantly different from the baseline.

Conclusions

After finalizing the results from this Phase II experiment, conclusions will be able to be drawn about the accuracy of the three portable ATISs for a short-term deployment. Accuracy measurement will be determined from the results of the data analysis. The null hypothesis will then be accepted or rejected.

APPENDIX C

HEADWAY EXPERIMENTAL DESIGN

EVALUATION OF HEADWAYS FROM PORTABLE CHANGEABLE MESSAGE SIGN (PCMS) MESSAGES

This headway experiment is a stand-alone document that will advise a future researcher in executing an investigation into the effect of PCMS messages on driver frustration and aggressive driving maneuvers. For this experiment, driver frustration and aggressive driving (e.g., tailgating) will be indirectly measured in terms of vehicle headway. More aggressive driving is correlated to shorter vehicle headways. An evaluation of literature has shown human factors investigations of PCMS messages has been done on the dynamic speed reduction systems (DSRS) side of portable advanced traveler information systems (ATIS). DSRS research has been done involving speed reduction and not headways or in the portable traveler delay systems (PTDS) field of portable ATIS. This experiment is intended to add to the body of knowledge in the human factors connection with PTDS.

Research Methods

The design of the experiment is focused on measuring the effects of PCMS messages on vehicle headways. The research methods section will cover the Research Objectives, Scope, and the Hypothesis Statement of the experiment.

Research Objectives

The objectives of this experiment are to develop a more in-depth understanding of the effectiveness of PCMS messages to reduce drivers' frustration and aggression with the use of portable ATIS. The understanding of PCMS message effectiveness will help traffic operations personnel select messages that will work best in their respected district.

It will also advance the area of research in this specific piece of ATIS technology and recommend continuing future research.

Scope

This research is aimed at furthering research in the human factors connection between PCMS message sequences and driver headways. The portable setting references a site without adequate fixed systems and with varying delays occur; such as in work zones. Investigated vehicles will be part of a vehicle platoon, where headways are less than or equal to 3 seconds as defined by Freedman (2009). This investigation will remove large headways that can skew the average headway values, which are often subject to two-lane highways, and focus on the vehicles following or affected by the vehicle directly in front of them. Tailgating occurs in the vehicle platoon and is defined as 2 seconds or less by Michael et al. (2009).

Hypothesis Statement

Previous research on ATIS portrays the benefits of reduced driver frustration and less aggressive driving maneuvers when advanced traffic information is provided to drivers. ATIS in portable settings research is currently in the deployment reliability stage for PTDS. DSRS research has shown PCMS messages effectively reduce traveler speeds. The original research experiment has shown ATIS can be accurate and reliable in a portable setting. Based on this research, it is speculated that driver frustration and aggression will be reduced (i.e., increase in headways) with the use of PCMS messages. The null hypothesis for this research is that given advanced traffic knowledge, people will drive less aggressively. The hypothesis statement is:

$$H_0: P_{T_i} = P_{T_E} \quad \text{Eq. 1}$$

$$H_1: P_{T_i} \neq P_{T_E} \quad \text{Eq. 2}$$

Where,

P_{T_i} = Percentage of tailgaters for investigated PCMS message set i

P_{T_E} = Percentage of tailgaters for existing conditions

i = Message sequence number

Research Procedure

The research procedure is broken into six sections: Site Location, Investigated ATIS, Site Setup, Independent/ Dependent Variables, PCMS Messages, Motorist Survey, Data Collection, Proposed Analysis, and Conclusions. The Site Location, Equipment, and Independent/ Dependent Variables are subject of the author and do not change the scope of the experiment if replaced or altered. The proposed analysis recommends several directions for analysis. The conclusion section summarizes the proposed experiment.

Site Location

Selection of the site location is critical to the effectiveness of the experiment to generate results. It is recommended that the site location have the following characteristics:

- Rural area without cellular phone coverage
- Minimum of one mile length but preferably approximately five miles
- Congested area or peak hour congestion
- Work zone area with detours or alternative routes available

A site with a higher level of service is acceptable; however, it will take a longer time to collect the minimum sample size. The Data Collection section will cover the sample size calculation.

The site should be a two-lane highway for easier data collection and analysis. Any additional lanes will lower the chances of constant congestion and could possibly overload some of the equipment. It is also important the construction on the site selected remains in the same area for the duration of the experiment to not introduce an extra factor.

Equipment

The data collection system will incorporate three pneumatic counters, one PCMS, and two portable ATISs (one travel time system and one speed system). It is recommended using the two highest performing portable ATISs of the Evaluation of ATISs Phase II experiment. Although different brands of counters will work sufficiently, it is suggested the use of JAMAR Technologies counters from prior successful use. The counters will be synced in time and will be setup to capture passing vehicles. The PCMS sign will display preloaded messages to warn drivers of the congestion ahead and possible delays. The preloaded messages are discussed in further detail in PCMS Messages.

Site Setup

Figure 1 below shows a proposed layout of the headway experiment. The layout of the experiment is dependent on the exact site location but it should follow a similar setup.

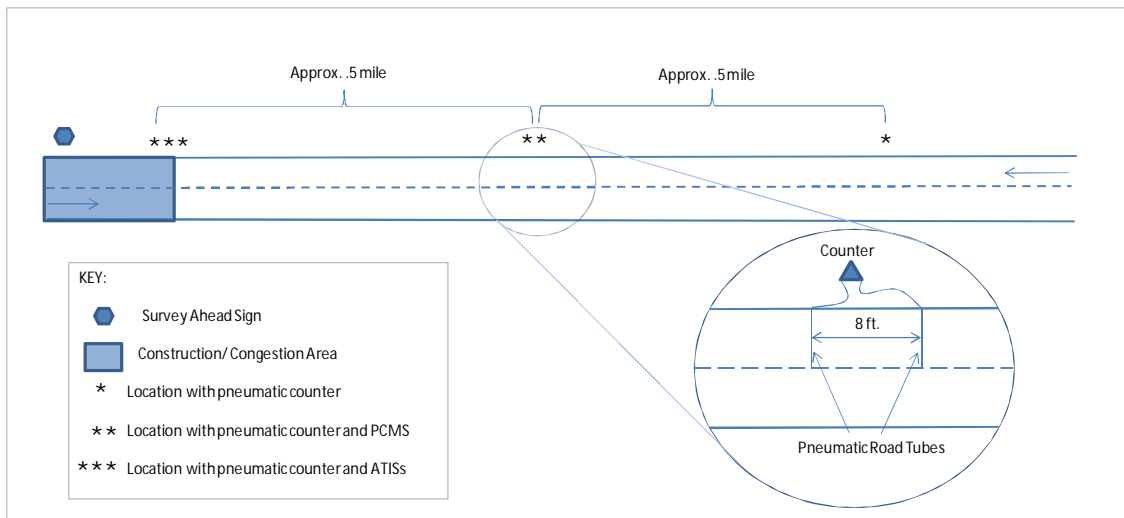


Figure 1: Proposed Site Layout

The “Survey Ahead” sign will be downstream of the last counter location. After this sign, preferably in a rest stop area, there will be a booth in the next access location that the drivers can fill out a motorist survey. The survey should be similar to the original survey with specifics updated. Additional questions can be found in Motorist Survey section.

Independent/ Dependent Variables

The independent variable for this experiment is the type of PCMS messages provided to the driver. They will be labeled as Message No. 1, Message No. 2, Message No. 3, and No Message. The dependent variable is the percentage of platooning vehicles that were tailgating as measured by vehicle headways.

PCMS Messages

Three different PCMS messages will be investigated as well as a blank PCMS. PCMS will be turned on arbitrarily long enough to capture the minimum sample size for all message sequences. Figure 2 shows the different investigated messages.

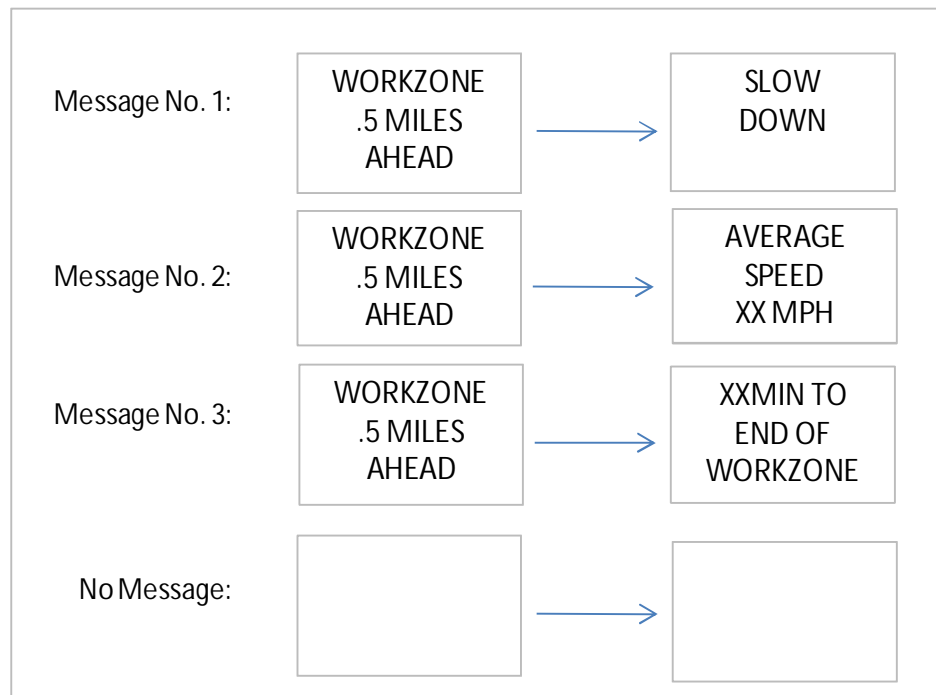


Figure 2: PCMS Messages

The PCMS will alternate between the two phases for each message number. The phases will alternate every two seconds. Once the minimum sample size is met for each message number, data collection will cease for the day until the next morning when the next message number will be investigated. Sample size calculations are described in the Data Collection section.

Motorist Survey

The “Survey Ahead” sign will be downstream of the last data collection location. After this sign, preferably in a rest stop area, there will be a booth in the next access location that the drivers can fill out a motorist survey. The survey should be similar to the original survey with specifics updated and the following questions included:

1. The message on the PCMS (Digital Message Sign) made me more cautious of the other drivers.
 - a. Strongly Disagree; b. Disagree; c. Neutral; d. Agree; e. Strongly Agree
2. The message on the PCMS was clear and concise.
 - a. Strongly Disagree; b. Disagree; c. Neutral; d. Agree; e. Strongly Agree
3. I am more patient of waiting for delay if I am informed prior to the congestion.
 - a. Strongly Disagree; b. Disagree; c. Neutral; d. Agree; e. Strongly Agree
4. I was aware of the congestion prior to the PCMS message.
 - a. Strongly Disagree; b. Disagree; c. Neutral; d. Agree; e. Strongly Agree
5. This was the first time I drove past the PCMS.
 - a. Yes; b. No; c. Unsure

Data Collection

The data will be collected at the three locations for all four message sequences. Data will also be collected prior to the deployment of the PCMS to capture the existing conditions. Prior to the existing conditions data collection, a pilot study should be executed to determine the standard deviation of headways to use in the sample size

calculation. It is recommended that 1.96 (two-tailed analysis) be used for the confidence interval and .1 seconds be used for the accepted range of error.

Table 1 shows the estimated number of hours required to capture the minimum number of vehicle headways. The time is separated into Class I and Class II two-lane highways for every level of service. A Class I highway would be a highway where motorists expect to travel at relatively high speeds, and a Class II highway would be a highway where motorists do not expect to travel at relatively high speeds (e.g., access routes, scenic and recreation routes, and rugged terrain). The Percent Time-Spent-Following (PTSF) values were referenced from the Highway Capacity Manual. The time values are estimates assuming a 500 passenger cars per hour flow rate and a 385 minimum sample size ($s=1$ second, $e=.1$ seconds, and $z=1.96$).

Table 1: Estimated Data Collection Time

LOS	Sample Size Collection			
	Class I Highway		Class II Highway	
	PTSF (%)	Time to N (hours)	PTSF (%)	Time to N (hours)
A	≤ 35	≥ 2.2	≤ 40	≥ 1.9
B	> 35-50	1.5-2.2	> 40-55	1.4-1.9
C	> 50-65	1.2-1.5	> 55-70	1.1-1.4
D	> 65-80	1.0-1.2	> 70-85	0.9-1.1
E	> 80	< 1.0	> 85	< 0.9

The data should be collected on weekdays with each investigated message number starting at 7 a.m. on the next weekday after the prior message number. This similar time of data collection will help to minimize the variable driving characteristics different hours of the day offer.

Proposed Analysis

Once the data collection is complete for all the message numbers, the analysis can begin. Raw vehicle data can be downloaded from all three counters and imported into Microsoft Excel or a similar program. From this point, vehicle headways can be calculated at all three locations for all four message numbers and the existing conditions.

Several different analyses can be done on the data collected. First, proportions of tailgaters for each message sequence can be calculated. These proportions can be compared to original existing proportions as discussed in Hypothesis Statement. Confidence bounds should be calculated and presented in results using the proportion t-test at a 95 percent confidence interval. Alternatively, average headway values of platooned vehicles for each message sequence can also be calculated. The sample mean t-test with an alpha value equal to .05 (two-tailed test) and the degrees of freedom equal to the sample size minus one should be used for the significance testing. The results of these tests should determine if the means of the groups are significantly different from the each other.

An additional analysis into the percentage of tailgaters with the PCMS on compared to the percentage of tailgaters with the PCMS off should be calculated. The percentages can be broken in different categories of speeds below the free flow speed (e.g., 0-10 mph, 10-20 mph, 20-30 mph). The sample mean t-test with an alpha value equal to .05 (two-tailed test) and the degrees of freedom equal to the sample size minus one should be used for the significance testing in this analysis. The results of these tests will determine when there is a significance difference of percentage of tailgaters when the PCMS is on compared to when it is off. These analysis results will provide the

information of when (i.e., measured speed below free flow speed) the PCMS should be activated to maximize the reduction of tailgaters. Additional analyses can be done at the researcher's discretion including survey responses.

Conclusions

Following the data analysis, conclusions will be able to be drawn about the effectiveness of PCMS messages to reduce driver frustration and aggression. In addition, a ranking of PCMS messages will be able to be compiled to determine the most effect messages. The null hypothesis statements will be rejected or accepted according to the analyses results.