ITS Pilot Project Demonstration Program Summary Report

Final Report

Division of Research
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15. SUPPLEMENTAL NOTES

Each evaluation contains a full report on the observations and analyses for each of the demonstrations.

16. ABSTRACT

The purpose of this contract is to conduct a technical performance analysis and operational evaluation of ITS projects demonstrated at the Innovative Mobility Experience Showcase in conjunction with the 2005 ITS World Congress. Some of these projects were demonstrated primarily as pilot projects for the California's Innovative Corridors Initiative (ICI). Partners who are respondents to the CFS have agreed to participate in a comprehensive evaluation of their respective projects to be conducted by the contractor of Caltrans choice.

Through the ICI demonstration projects, Caltrans and the San Francisco Bay Area MTC worked successfully with private-sector technology companies to deploy and demonstrate innovative technologies for ITS in California.

Seven separate demonstration projects were evaluated that could enhance data collection, data processing, and data dissemination. As detailed in the final report, these evaluations summarized the technical results of findings, and presented a table of pros and cons in the recommendations that may be helpful to decision-makers in moving forward with the particular product or technology.

The objective was not to approve or reject any of these products or system but to identify the pro and cons of each but to identify the pros and cons of each in terms of the questions raised in Section 1.2 of the Project Objectives of the final report: whether the product function as purported by the Vendor; and if the data accurate and useable.

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ITS Pilot Project Demonstration

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ITS Pilot Project Evaluation

Program Summary Report

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Program Summary Report

1. Introduction

This report summarizes the results of the technical evaluation of Innovative Corridors Initiative (ICI) demonstration projects in California deployed by the California Department of Transportation (Caltrans) and the San Francisco Bay Area Metropolitan Transportation Commission (MTC).

1.1 Project Origination

Caltrans and its regional partners are interested in deploying ITS technologies and services in conjunction with industry representatives. ICI was a program designed to encourage the early deployment of innovative technologies for ITS in California. Through ICI, Caltrans and its regional partners issued a Call for Submissions (CFS) inviting technology representatives to submit proposals to deploy ITS technology in a demonstration setting to share data and information collected with the public sector in return for access to the Caltrans right-of-way and data not normally granted to the private sector. These technology representatives were required to self-fund the pilot demonstrations through an agreed-upon duration. In exchange, they were able to test their products and services in a real-world setting, showcase them at the 2005 ITS World Congress in San Francisco, California, and be evaluated by an independent observer. The CFS resulted in 28 proposals from 16 private companies that could enhance data collection, data processing, and data dissemination. Ultimately, seven companies representing eight projects were selected to enter into a contractual agreement with Caltrans to conduct demonstrations.

1.2 Project Objective

The objective of the evaluation project is to assess the technical feasibility and functionality of the demonstration technologies as they pertain to safety, efficiency, reliability, accuracy, mobility, cost-effectiveness, system management and integration. The ICI demonstration projects evaluated are related to data collection, transmission, processing, or dissemination. The project and supporting vendor are listed below:

1) TV511 – Tele Atlas
2) Wireless Data Solutions – ENCOM
3) Dynamic Route Advisory System – Circumnav Networks (now Dash Technologies)
4) Intelligent Loop Detector – Infotek Associates
5) 511 Level Two– NAVTEQ

6) Vehicle Infrastructure Cooperation (VIC) – NAVTEQ
7) Bay Area Web Congestion Mapping and Traffic Forecasting – Outreach
8) Speed Sensor Demonstration – SpeedInfo

The eight projects above were also deployed together as a working system. The data flow between the projects and the public agencies involved is shown in Figure 1 below.

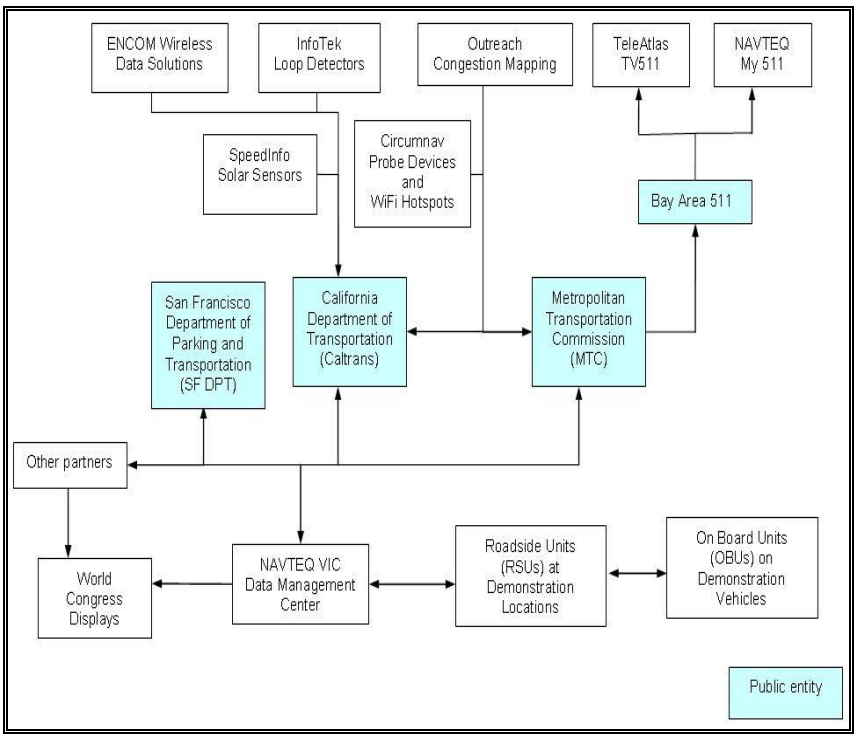

Figure 1: Data Flows

Each ICI demonstration project is unique and each evaluation required a customized evaluation criteria that focuses on aspects of hardware, software, and end users. The evaluation for these projects sought to answer the following questions:

- Does the product function as purported by the Vendor in the CFS responses?
- Is the data accurate and reliable?

1.3 Evaluation Approach

A standard evaluation approach and format was developed for program consistency and to facilitate comparisons between various projects. Each report is divided into an *Evaluation Summary* and an *Evaluation Details* section. The *Evaluation Summary* section includes the main points and results of the *Evaluation Details* section. The format of the *Evaluation Details* section was standardized as follows:

1. **Delivery**—This section includes vendor's stated objective as well as additional assertions and long-term goals in the Caltrans contract.
2. **Project Specifics**—This section includes the locations, dates, and times of the deployment and evaluation.
3. **Technology**—This section includes a description of the technology or system being evaluated as well as the results of previous deployments.
4. **Performance Measures**—The results of each evaluation included Quantitative Outputs, Qualitative Outputs, and Other Performance Factors. The information was mostly presented in response to specific questions. The project performance measures for each individual project were also related to Caltrans' 9 performance measures, indicating Caltrans' ones were applicable.
5. **Evaluation Methodology**—This section summarizes the evaluation methodology process.
6. **Evaluation Results**—This section includes the results from the data gathering and data analysis.
7. **Recommendation to Caltrans**—A table of pros and cons was used to summarized the information gathered by the evaluation.

Each evaluation included a review of the 9 Caltrans Performance Measures, simply indicating which Caltrans measures were applicable.

For projects that were primarily data collection, the performance evaluation was based on accuracy. For other projects that represent system demonstrations, the performance evaluation was based on technology and system integration, ease of use, and benefits to agencies or end users. The specific elements that were evaluated for each demonstration project are described in further detail below.

2. Project Participants

This section briefly introduces each product and technical features that are being demonstrated.

2.1 TeleAtlas TV511

TeleAtlas developed a sequence of traffic images and information called TV511 that provides continuous real-time traffic and incident data for Bay Area freeways. This information plans to include real-time traffic, transit, road conditions, and road-weather information based on information from 511 and CHP. The program was developed in coordination with KMTP TV32 with an intended air time from 5 AM to 8 AM weekdays. The program combines incidents displayed on local maps with voice and on-screen text.

2.2 ENCOM Wireless

ENCOM wireless data modems provide wireless communications between traffic monitoring and control systems as a substitute to hardwire communications. ENCOM products use license free, frequency hopping spread spectrum (FHSS) technology. ENCOM's 2000 series modems are designed to collect and transfer multiple contact closure information from any remote detection or monitoring system such as a Ramp Metering System (RMS) to a master controller. The technology allows multiple transmitters to communicate to a single receiver allowing a single Transportation Management System (TMS)/RMS controller to serve multiple detection locations. The objective of this technology as stated by the vendor is to provide a cost-effective alternative to lengthy cables between detector stations, provide easier and less disruptive deployment as compared to hardwire communication, maximize the deployment location flexibility, and reduce the cost of equipment at multiple detections locations.

2.3 Circumnav Networks (now Dash Navigation)

Circumnav Networks, Inc. (now Dash Navigation) developed a technology that allows two-way communication of traffic data between vehicles and roadside devices. The system is designed so that probe data that includes speed and direction of travel can be sent from the vehicle to a fixed roadside access point (roadside unit). The roadside unit sends real-time traffic conditions back to the vehicle. Additionally, vehicle-to-vehicle communications are also possible using Wi-Fi technology and software. The probe data gathered by the vehicles is combined with speed data from 511 services to create a comprehensive database of real-time speed data. The data is sent to the vehicles and utilized by a navigation device to display real-time route guidance and estimated travel times. Communication between each roadside access point and the Circumnav servers is achieved through cellular technologies. For the ITS World Congress demonstration, Circumnav installed several fixed access points along Bay Area highways.

2.4 Infotek

The Intelligent Loop Detector processes raw loop detector data from the field and then sends post-processed information wirelessly to a Transportation Management Center (TMC). This is a potentially economical solution versus using a traffic signal controller to collect, process, and transmit data. The post-processed information will be small compared to the raw loop data and therefore much easier and faster to transmit over a wireless network. Post-processed information includes spot speeds and number of long vehicles (based on volume and occupancy data).

2.5 NAVTEQ – 511 Level Two

The 511 Level Two application is an enhancement to the existing Bay Area 511 traveler information system which offers personalized services based on individual user needs, and leverages NAVTEQ's digital map coverage. The application consists of a voice recognition interface; customized personal identification number (PIN) capability which allows user to "store" directions and access them at another time; door-to-door driving directions for the entire Bay Area; the ability to select address or point of interest (POI) as origin and destination; the ability to determine parking garage space availability; and make parking reservations in real-time.

2.6 NAVTEC – Vehicle Infrastructure Cooperation (VIC)

The Vehicle Infrastructure Cooperation deployment is a physical Proof of Concept demonstration of vehicle-to-roadside communication concepts. The VIC deployment demonstrates various Vehicle Infrastructure Integration (VII) concepts such as centralized data processing and disseminating capability, common location referencing, and physical infrastructure deployment. The deployment consists of the following three main elements: the VII Data Processing Center - a central shared repository for probe vehicle data; the Map Display application and Common Location Referencing which allowes NAVTEQ and the partners to provide standardized location references and display real-time incident information; and the actual infrastructure consisting of 12 roadside units (RSUs) throughout San Francisco city streets.

2.7 Outreach – Probe Vehicle Technology

Outreach, a non-profit paratransit service, designed a website that aggregates speed data from several sources and displays both real-time and forecasted roadway speeds. Existing data sources include fixed roadway sensors, traffic incidents, and private fleet data. Additional speed data is acquired from volunteer drivers who download Outreach software onto their Personal Digital Assistant (PDA) with Bluetooth Global Positioning System (GPS) capability. The PDAs, with Bluetooth GPS and the Outreach software, are capable of measuring a vehicle's speed, determining its location, and then sending that information back to the Outreach server. All of the information is collected by a "virtual loop detector" to hold real-time and historical speed data for major highways, major arterials, and streets. The data archive is used to forecast roadway speeds for each segment. The Outreach approach is similar to 511's approach in aggregating information from Caltrans loop detectors and California Highway Patrol Computer-Aided Dispatch (CHP CAD) for display to the public. Outreach also proposes to add new sources of probe data such as transit fleets, commercial fleets, and volunteer drivers.

2.8 SpeedInfo

SpeedInfo uses Doppler radar technology to obtain speed data. Data is collected using sensors mounted on existing poles within Caltrans right-of-way on the side of the freeway. The data is transmitted to a central server via a cellular network. SpeedInfo reviews the accuracy of the data and formats it for delivery to their partners. The data is merged with publicly available traffic data in order to process the data and format it for the end user. In the context of this pilot project, Nearly 300 SpeedInfo sensors were installed at locations where Caltrans loops do not exist in the Bay area. Sensors have also been installed at a few locations where Caltrans loops are present. A sample from the overlapping locations was used in the evaluation.

3. Summary of Evaluation Findings

Each evaluation contains a full report on the observations and analyses for each of the demonstrations. The objective of the evaluation was not to approve or reject any of these products or systems; rather, it is to identify the pros and cons of each in terms of the questions raised in Section 1.2 Project Objectives of this report: whether the product function as purported by the Vendor; and if the data accurate and useable.

The full FINAL reports of each evaluation are included as Appendix A. The focus of the evaluation findings are summarized below as well as the pros and cons in the recommendations to Caltrans that may be helpful to decision-makers in moving forward with the particular product or technology.

TV511 Demonstration – TeleAtlas

The TV511 evaluation focused on the benefit that the program provides for traffic information dissemination and the reliability of the information. Factors included the delay in incident posting, ease of relevant data recognition, and the accuracy and breadth of data. The reliability of the system considered the chance of failure or inconsistency between 511 data and TV511 data.

PROS	CONS
Provides enhanced incident information without the use of computer/ internet access	Requires sponsorship for broadcast
Displays incident information effectively with coordinated voice and text displays	Does not include transit, travel time, speed data, or slowdown incidents
Information is nearly identical to what is posted on 511.org and SFgate.com	Cannot provide user-customized information like the 511.org website and phone service
Quickly cycles through all Bay Area incidents (every 3-5 minutes)	Viewer required to watch non-relevant information to obtain desired information
Updates incident information as it is received	Some delay incurred in displaying a percentage of incidents

Wireless Data Solutions – ENCOM

ENCOM demonstrated the replacement of hardwire communications between a telephone demarcation cabinets and a Model 170 controllers and between two Model 170 controllers. The following three locations were included in the evaluation:

- Valley Blvd On Ramp at I-10 EB, City of El Monte, California
- Baldwin Ave On Ramp at I-10 EB, City of El Monte, California
- Madre St Ramps at I-210 EB, City of Pasadena, California

The quantitative results compared the controller communications rates with the hardwire connection in place and with wireless connection in place, while the qualitative results included a discussion of factors that would affect the wireless communications rate and additional maintenance considerations.

PROS	CONS
Does not require trenching or directional drilling for installation of conduit; avoids traffic disruption due to conduit installation	Requires near line of sight between antennas free of obstructions due to buildings and vegetation.
May be less expensive in situations where conduit installation is expensive or difficult to install.	Additional ongoing troubleshooting/ equipment configuration may be required over hardwire connections.
Can be installed more quickly than when conduit installation is required; useful as a temporary solution when hardwire communication cables are broken or are	Increased maintenance to trim vegetation could be needed to maintain line of sight.

removed during construction.	
Uses RS232 and FSK protocols commonly used by traffic controllers.	Line of sight could be blocked by future buildings.
Utilizes license-free, low-power frequencies for communications.	Antennas might attract unwanted attention to cabinets; issues related to damage and theft of equipment might arise.
Can handle point-to-point and point-to-multipoint configurations.	Drilling holes in the cabinet walls could be required for antenna cables; these holes are additional location for dirt, dust and moisture to enter cabinet. If ENCOM equipment is relocated to another location, these holes would need to be sealed.

Dynamic Route Advisory System – Circumnav (Dash Technologies)

This evaluation focused on the accuracy and reliability of the two-way data communications between the vehicle and the roadside unit. The evaluation also considered vehicle to vehicle data transfer. The data collection focused on observing the installation and maintenance of the equipment and on the data transfer between the vehicle and the roadside unit. Installation and maintenance results were based on field visits to typical roadside units and observation/examination of the vehicle equipment. Results regarding the range and speed of the data transfer were provided by the vendor.

PROS	CONS
Allows in-vehicle visual access to real-time traffic data	It requires a large number of probe vehicles and roadside devices to obtain valid data
Collects traffic data from probe vehicles, including information on major arterials	Recurring cellular connection costs to roadside units
Allows for map and yellow pages updates without user involvement	There may be a capacity limit of how many vehicles can communicate with each other and a single roadside device .
Allows data to be transmitted between passing cars and between vehicles and roadside devices	Topography, roadway curvature and speed differential may impact the communications performance shown in the trial data.
Can determine and distribute arterial roadway traffic conditions	Limited evaluation data available for vehicle-to-roadside communications.
Wi-Fi connections allow vehicle-to-roadside and vehicle-to-vehicle communication allows sharing of traffic information without incurring cellular data costs.	Currently the road side units are installed with call boxes. While call boxes are phasing out, feasible location for road side units may be difficult to determine.
New road construction and improvements information can be automatically determined and distributed by system	
Minimal installation cost and impact to existing roadway equipment.	

Intelligent Loop Detector – Infotek

This evaluation focused on the feasibility and accuracy of processing loop data in the field rather than at the TMC. There were two deployment locations for Infotek in the context of this pilot project: Three locations were in Caltrans District 4 (San Francisco Bay Area) that focused on Volume, Speed, and Occupancy information using loops in dual-loop configuration, and three locations were in Caltrans District 7 (Los Angeles and Ventura County) that focused on detection of long vehicles using loops in single-loop configuration. The evaluation process compared post-processed Infotek information (volume, speed, occupancy, truck counts) with one or more of the following:

- Output from Traffic Management Center after processing raw data;
- Output from Caltrans Performance Monitoring System (PeMS) records;
- Manual counts (from video tape)

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PROS	CONS
Total daily volume data closely matches manual counts.	Requires field calibration of Caltrans detector cards at each deployment location.
Can provide vehicle classification (length data) from single-loop and dual-loop detector configurations.	Accuracy of results may vary based on variance in volume or speed.
Provides cellular communications link to field controllers. Useful for items like cabinet and detector rack remote reset.	Recurring cellular communications costs.
Includes loop diagnostic tools	
May be less expensive than 170/2070 controller	
Device is programmable and format of data can be easily changed based on user needs.	

511 Level Two– NAVTEQ

The parking space availability and parking space reservation elements were not deployed in this demonstration. The evaluation for the other elements of the NAVTEQ 511 Level Two system considered the following three key elements:

- Data Accuracy (accuracy of directions or parking availability information, voice recognition, and dropped calls)
- Integration with existing Bay Area 511
- User Satisfaction and Usability (user's ability to navigate through the 511 Level Two system; possible delay caused by an abundance of POI choices,

granularity of directions, complexity of system, ability to save preset routes for personalized service).

These items were assessed by making sample requests using the 511 Level Two services by telephone. System failures such as hang-ups or system down time were noted to quantify system reliability.

PROS	CONS
Covers route information for entire country	Difficult to interpret and utilize some of the directions provided due to occasionally inaccurate traveling distance and cardinal directions
Directions provided similar to those available through commercial websites such as maps.yahoo.com and mapquest.com	Sometimes difficult to communicate with computerized voice system
Saves last direction request and allows access to the same direction	Menu navigation could use improvement so that the users would not spend long time to locate the information they need
Numerous points of interest	Accepts non-existent addresses
Low disconnection rate	Does not yet incorporate real-time traffic data in traveling directions, while main 511 system has real-time data capability
	Smallest increment of ¼ mile can misguide user

Vehicle-Infrastructure Cooperation (VIC) – NAVTEQ

The demonstration project was not deployed and could not be evaluated.

Bay Area Web Congestion Mapping and Traffic Forecasting – Outreach

While the Outreach system was the original focus of this evaluation, Outreach was not able to continue the demonstration after the 2005 ITS World Congress due to a loss of financial commitment. As a result, the evaluation was revised to include a review of the Outreach System report and research into the planned deployment of cellular phone-based and PDA/ GPS-based probe vehicle technologies around the country. In addition to the Outreach system, information was gathered on planned deployments in the following locations:

- Atlanta, Georgia (cellular phone-based)
- Baltimore, Maryland (cellular phone-based, GPS-based on fleet vehicles)
- Missouri (cellular phone-based)
- Portland, Oregon (GPS-based on transit vehicles)

The evaluation included interviews with public agencies that are currently using or might use such information in their deployments of real-time information to determine what steps would be needed to integrate this information and identify any obstacles by using such information. Due to the fact that probe vehicle technology is still largely an emerging technology, there is very little tangible data that is available.

PROS	CONS
Traffic probes present the opportunity for another source of traffic data.	Algorithms for correlating probe data to roadway speeds and travel times still under development.
Less calculation required to determine travel time of an individual vehicle for a segment.	Dependent on sufficient volume of probe vehicles to produce accurate and reliable data.
Installation of equipment is less disruptive and less expensive than installation of loop detectors or other point-based vehicle detection devices.	Public will have privacy concerns about probe technologies.
Relies on existing cellular networks and/or GPS so can be deployed to cover a larger area quickly.	Privacy concerns may limit the willingness of cellular phone providers to be associated with cellular-phone-based tracking.
System could cover arterial streets network which is typically not monitored by traditional traffic monitoring technologies.	Currently, GPS-based devices are not common among drivers.
Cellular phones are common among motorists. GPS-based devices (including new cellular phones) are becoming common.	Lack of standards or protocols for data exchange increase costs for agency to switch to new probe vehicle provider.
Opportunity for private/ public partnership.	

Speed Sensor – SpeedInfo

This evaluation focused on accuracy of data collected from roadside sensors in comparison to other data collection sources. Data from the following two locations was included in the evaluation.

- I-80 E between Gilman Street and Golden Gate Fields & I-80 E between Golden Gate Fields and Central Avenue
- I-80 W between Golden Gate Fields and Gilman Street

The SpeedInfo data was compared to other data (i.e., Caltrans loop data, GPS "floating car" run data) to measure accuracy, reliability, and productivity. A portion of the evaluation also looked at the reliability of data disseminated on the SpeedInfo website (www.speedinfo.com). Other areas of evaluation included integration compatibility with

existing data sources, costs for installation and maintenance, and scalability of the system.

PROS	CONS
Provides ability to access data at locations without data infrastructure in place.	Relies on cellular networks so the performance relies on an outside service
Low power requirements and runs on solar power.	Crystal device failure cannot be predicted but may have been resolved.
Ease of installation and configuration into an existing system.	Currently provides only an average speed per sample size.
Uses proven Doppler technology.	
Easy data access for public via website.	

4. Lessons Learned

This demonstration project is the first of its type conducted by Caltrans. As a result, there were numerous lessons learned in the process of completing the project. These are presented below, along with some ideas for adjustments that may help to address these issues on future projects. These ideas may or may not be feasible depending on the particular conditions and details for a future project.

1. ***There is little incentive for vendor action without compensation or recognition.*** The vendors that responded and were selected to participate in this ICI program were not compensated for their labor or equipment in this demonstration, and the primary recognition for this project was from the ITS World Congress event. As a result, it was difficult at times to observe progress in the demonstration and the schedule would often be delayed. Further, several vendors discontinued their demonstration efforts due to a lack of funding support toward the demonstration. This all became particularly evident after the conclusion of the ITS World Congress with no future event for showcasing the product or technology.

   Ideas for Improvement:
   - Include financial compensation in contract.
   - Schedule evaluation to be completed before or shortly after a showcase event.
   - Require vendor to give more advance notice of major changes in or cancellation of deployment plan.

2. ***Starting project close to major showcase event reduced the vendor resources available for the evaluation.***
   The project kick-off meeting was held in September 2005 when vendors were also busy preparing for the ITS World Congress showcase event in early November 2005. The importance and marketing opportunity of the ITS World Congress resulted in vendors focusing their time and/or resources toward the ITS World Congress set-up rather than the evaluation project.

   Ideas for Improvement:
   - Start working with vendors well before a showcase event.
   - Consultant and/or Caltrans to visit and/or observe the vendor staff or group responsible for demonstration project to understand vendor processes and available data.

3. ***Vendor staff changed through the course of the project.***
   For some of the demonstration projects, there were changes the Vendor project staff that introduced some confusion or delayed response as the new staff became acquainted with the project and recent decisions.

   Ideas for Improvement:
   - Include two vendor contacts for each project.
   - Provide clear and regular documentation of expectations and action items of all project participants (vendor, Caltrans, consultant, etc.)

4. ***There were changes in vendor deployments.***
   Since the project is primarily driven by the Vendor's interests, there were occasions where a vendor decided not to move forward with the demonstration or abandoned a particular technology that was part of the demonstration for a newer technology. This affected the approach that was taken in the evaluation. In these instances, KHA worked with the stakeholders to determine what information was available from the vendor and whether the evaluation should be continued. For the evaluations that were continued, the scope was modified to fit the available data. In one case, the evaluation was expanded to look at other deployments of probe vehicle deployments outside of California.

   Ideas for Improvement:
   - Clarify expectations up-front of what would be expected from vendor and consultant in case of a changed deployment plan.
   - Require vendor to give more advance notice of major changes in or cancellation of deployment plan.
   - Stakeholders and Consultant to conference quickly after change in deployment plan.

5. ***Obtaining and confirming a reliable independent data source was difficult.***
Some demonstrations produced data whose accuracy needed to be evaluated. The evaluation approach relied on using existing data sources or data that could easily be collected. However, such data was not always available, it was difficult to confirm the available data's accuracy, or the data did not quite match the vendor data (e.g. different format, location, timing, etc.). Without reliable baseline data, it is very difficult to confidently evaluate the accuracy of vendor data. In one of the cases, there might have been an opportunity to install the demonstration equipment in closer proximity to another independent data source (loop detector station) in order to improve the confidence level of the comparison if this data source was identified prior to the installation.

Ideas for Improvement:

- Ask vendor for suggestions of existing independent data sources prior to installation of project demonstration equipment.
- Obtain buy-in from vendor of evaluation baseline data prior to starting the evaluation process.
- Document the data format that is being expected from the Vendor prior to start of evaluation.
- Consultant and/or Caltrans to visit and/or observe the vendor staff or group responsible for demonstration project to understand vendor processes and available data.
- Increase budget to allow for additional new data collection.

6. ***Vendor expressed concerns over evaluation methodology after evaluation had been completed.***
For some demonstrations, the vendors expressed concerns about the evaluation methodology after seeing the DRAFT evaluation report, although they had been given the opportunity to review the evaluation plan. When schedule and budget allowed, these concerns were addressed in the FINAL evaluation report.

Ideas for Improvement:

- Provide a one-page summary of the evaluation specifics (in addition to the evaluation plan) for Caltrans and Vendor to review prior to beginning evaluation.
- Obtain buy-in from vendor of evaluation baseline data prior to starting the evaluation process.
- Consultant and/or Caltrans to visit and/or observe the vendor staff or group responsible for demonstration project to understand vendor processes and available data.

5. Conclusion

Through the Innovative Corridors Initiative (ICI) demonstration projects, the California Department of Transportation (Caltrans) and the San Francisco Bay Area Metropolitan Transportation Commission (MTC) worked successfully with private-sector technology companies to deploy and demonstrate innovative technologies for ITS in California. Seven separate demonstration projects were evaluated that could enhance data collection, data processing, and data dissemination. These evaluations summarized the technical results of findings, and presented a table of pros and cons in the recommendations that may be helpful to decision-makers in moving forward with the particular product or technology.

This demonstration project is the first of its type conducted by Caltrans, and there were numerous lessons learned in the process of completing the project. These lessons and the ideas for improvement will be helpful in the scoping and management of future similar projects.

ITS Pilot Project Demonstration Program Summary Report

APPENDIX A: EVALUATION REPORTS

ITS Pilot Project Demonstration

TV511
Evaluation

Prepared for
Caltrans

June 2006
FINAL

Prepared By
Kimley-Horn and Associates

ITS Pilot Project Evaluation

TV511

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Evaluation Summary

Vendor/Project – Tele Atlas North America, Inc./TV511 Demonstration

TeleAtlas and KMTP jointly produced and broadcast real-time traffic and transit information on over-the-air and cable TV. The TV511 program combines computer-generated voice and on-screen text with maps indicating the locations and types of traffic incidents. There are five different coverage maps – one overview and four detailed – covering the Bay Area. The program continuously cycles with updated information.

Delivery: Does demonstration satisfy Vendor's stated objectives for Caltrans?

Vendor's stated objectives:

- *Provide real-time transit and traffic data via broadcast television*
- *Allow viewers to obtain relevant information within 2-4 minutes of turning on the program*

TV511 was broadcast on KMTP during 2005 ITS World Congress (November 2005) for a period of six days. After that period, KMTP discontinued the broadcast in favor of more popular programming. TeleAtlas provided an XML feed to Kimley-Horn that allowed viewing of the TV511 loop via the internet. Real-time traffic incident data is included in the provided TV511 feed. No transit information is included in the service.

Key Observations

- **Capabilities of Technology**
  - **The technology is very sound and effective at informing the viewer of traffic incidents in the Bay Area via television. Nearly all observed incidents observed at 511.org or SFgate.com websites were included in the TV511 feed with minimal delay. The voice matched the text for all but one observed incident (71 observations) even with a wide variety of incident descriptions.**
  - **Certain types of traffic alerts, displayed on both 511.org and SFgate.com, were not displayed by TV511 at any point during the program. Missed information included Caltrans construction projects, a major event alert, and severe traffic alert/emergency road closures. During each of the three peak periods evaluated, two long-term construction-related road closures were not included. In addition, an event at the Cow Palace and two severe traffic alerts/road closures were not displayed by the system.**
  - **There are several missing features offered in the original contract that should be added to provide additional benefit to the viewer, such as speed information and transit information. According to**

TeleAtlas, the program could be improved relatively easily to include these additional features.

- **It would be beneficial for the service to allow bulletins to be posted remotely by 511 staff, which would require some day-to-day effort by 511 staff to enter the messages. This would require minor changes to the software program. However, if these messages are sent directly to the TV511 server, they would not be included in the 511 database since the communications between the 511 database and the TV511 Server are one-way only.**

- **Ease of setup/maintenance**
  - **The system is simple to initialize and operate. A computer at the broadcast station with an internet connection to the TV511 server is required. TeleAtlas provides an installation CD for placing the TV511 program on the computer and configuring the connection to the TV511 server. Installing the program takes approximately 20 minutes after which the output for the computer is ready for display on a computer monitor or to be broadcast.**
  - **Day-to-day maintenance by broadcast partner is not required (beyond maintenance of the computer and internet connection). The maintenance of the TeleAtlas server and connection with 511 is borne by TeleAtlas.**
  - **The TeleAtlas server allows easy expansion to numerous broadcast partners. TeleAtlas approximates a one-time installation cost between $10,000 and $25,000 per partner to cover initial set-up, equipment and configuration costs. This cost is dependent on the technology and labor required to interface TV511's technology with that of the broadcast partner.**

- **Broadcast Partners**
  - **The TV511 program was aired on television (UHF Channel 32 and cable) during the 2005 ITS World Congress for a period of six days. Immediately following the conclusion of the World Congress, it was replaced by other programming on KMTP. According to TeleAtlas, KMTP received numerous complaints when its other programming was temporarily suspended to show the TV511 broadcast. KMTP could not be reached to discuss the TV511 broadcast.**
  - **TeleAtlas suggested using city cable channels to attempt to reach viewers with the program. A similar approach is currently in use in Phoenix, AZ, and may be utilized in St. Louis, MO.**
  - **The difficulty of finding a broadcast partner is a significant downside to this technology. If no sponsor is found, it is difficult for a television station to broadcast TV511 instead of a program that**

has funding support (usually through advertising). The broadcast partner is likely to replace the TV511 broadcast with paid programming or more popular programming. Sponsorship would negate this concern. According to TeleAtlas, if they use KMTP, they would need sponsorship of approximately $200,000 per year to cover airtime and other costs. If city cable channels are used (assuming that "airtime" on these channels is provided at no cost), sponsorship of about $10,000 per city per year, depending on the number of cities, would be needed to procure TeleAtlas' involvement.

Recommendation to Caltrans

PROS	CONS
Provides enhanced incident information without the use of computer/ internet access	Requires sponsorship for broadcast
Displays incident information effectively with coordinated voice and text displays	Does not include transit, travel time, speed data, or slowdown incidents
Information is nearly identical to what is posted on 511.org and SFgate.com	Cannot provide user-customized information like the 511.org website and phone service
Quickly cycles through all Bay Area incidents (every 3-5 minutes)	Viewer required to watch non-relevant information to obtain desired information
Updates incident information as it is received	Some delay incurred in displaying a percentage of incidents
Simple initialization with little to no maintenance	
Potential for revenue generation through sponsorship	

Evaluation Details

1. Delivery

Vendor's Stated Objective
In Caltrans contract: r *Provide real-time traffic, transit, road conditions, and road-weather information utilizing maps, voice and on-screen text* r *Display program continuously between at least 5 to 8 a.m. on KMTP* r *Allow viewers to obtain relevant information within a few minutes of turning to program* r *Aid viewers in making travel mode, schedule, and route decisions* r *Make program available to 2 million households in Bay Area* *Additional Assertions:* r *Launch as part of 12th World Congress on ITS*

2. Project Specifics

Deployment Date(s) and Time(s)	Evaluation dates, times & weather conditions
November, 2005 (one week as part of ITS World Congress)	**April 12, 2006 PM Peak – rain April 13, 2006 AM Peak – no rain April 27, 2006 PM Peak – no rain April 28, 2006 Mid-day – no rain**
Deployment Location(s)	Evaluation Location(s)
San Francisco Bay Area: KMTP (UHF Channel 32, Cable TV)	**San Francisco Bay Area State highway network**

3. Technology

3.1 Technology or System Description

TV511 utilizes data from the 511 database to create the displays and text. It provides Bay Area visitors and residents another option besides the telephone and the internet to access real-time traffic and transit data.

The TV511 Architecture requires interaction between TV511 and the 511 system. TV511 has a Program Control Workstation at 511 facilities in Oakland, CA. The 511 Database Server communicates via XML and a formatted interface with the TV511 Database Server at TeleAtlas facilities in Menlo Park, CA. The TV511 Program Control Workstation and the TV511 Database Server send information over the internet to the TV511 Television Server at KMTP headquarters in San Francisco, CA. This server then sends information to the KMTP UHF Broadcast Transmitter, which provides information to Bay Area televisions via airwaves and cable.

Five coverage maps have been selected for on-screen display: Bay Area Overview, North Bay, Peninsula, East Bay, and South Bay. These maps will display real-time traffic, transit, road conditions, and road-weather information.

3.2 Previous Evaluations (including vendor's own) and/or Similar Technology Deployments

A similar product, called Traffic Check, was implemented in 1999 by Etak, the predecessor to TeleAtlas, and broadcast on KMTP. This program used data collected by Metro Networks, which utilized local reporters, government agencies, operations studios, mobile units, and a fleet of airplanes to gather its data. Similar to the current program, the displays and voice narration were automatically generated. The program initially aired from 5 a.m. to 9 a.m. on weekdays on KMTP.

A similar program is currently deployed on several cities throughout the country. It currently airs on four city cable stations in the Phoenix, AZ area. A similar system ran for a couple years in Atlanta, GA beginning with the 1996 Summer Olympics. According to TeleAtlas, the system has been well received in these cities. The Atlanta version was operated until it became obsolete, and no update to the system was pursued. The St. Louis, MO, area is an anticipated site for future deployment.

4. Performance Measures

Performance measures are defined here for this project and are divided into different categories for evaluation and discussion: Quantitative, Qualitative, and Other Performance Factors.

Definition of Performance Measures

What does the technology or system measure?

According to the vendor, the TV511 program makes 511 traffic and transit information available via television in the Bay Area, but does not collect or measure information on its own.

4.1 Quantitative Outputs

Accuracy

1. What is the delay between the time 511 receives traffic information and when that information is displayed by TV511?

   Of the 17 incidents that appeared in the first evaluation PM peak hour, only three had any delay between when they appeared on the 511.org site and when they were added to the TV511 system. The delay for these three ranged from 7 to 16 minutes.

   Of the 18 incidents that appeared in the second evaluation PM peak hour, six had delay that ranged from 3 to 59 minutes. Of the 9 incidents that appeared during evaluation in the a.m. peak hour, four had a delay ranging from 13 to 29 minutes between when they were displayed the 511.org website and TV511.

   It appears that the 511.org database is not completely synchronized with the database(s) that TV511 and SFgate.com obtain information from. In one instance, a disabled vehicle on NB 101 at Miraposa and a vehicle fire incident on Highway 4 were shown 16 and 20 minutes, respectively, later on TV511 than when they were listed on 511.org. The posting time nearly matched for SFgate.com and TV511, indicating that the delay is likely due to the output database from 511, not TV511. Therefore, while the incident information is the same, the 511.org and TV511 databases are not identical. This is beyond the control of TeleAtlas.

2. What is the lag time between the visual displayed by a traffic camera and when it is shown on TV511?

   Feature not included in system.

3. What is the delay between when transit incidents or problems occur and when they are displayed by the program?

   Feature not included in system.

4. Is the visual information displayed by the program consistent with the data provided via telephone and internet by 511? ☒ YES ☐ NO

5. Is the audio information consistent with the visual information? ☒ YES ☐ NO

There is an impressive variety of phrases used by the computer-generated audio. In all but one case, the audio matched the text provided on-screen. For an incident on Van Ness, the audio skipped over the word "Van Ness," saying "Road work eastbound at Lombard Street in San Francisco" instead of "Road work eastbound at Lombard Street *[Van Ness]* in San Francisco."

Reliability

1. Did the KMTP server or transmission fail at any point during the evaluation?

   Did not test this during ITS World Congress. Subsequent evaluation was performed using internet feed to a personal computer, where there was no failure in obtaining the information. TV511 is not currently being aired by KMTP.

2. Did the TV511 server fail at any point during the evaluation? ☐ YES ☒ NO

Productivity

1. What is the maximum amount of time that a person will need to watch the program to find the information they are seeking?
   The length of broadcast varies by the number of incidents at that time. During an average peak traffic period, the program will have a cycle length of 2 to 4.5 minutes, including a 30 second advertisement period.

2. What is the average amount of time that a person will need to watch the program to find the information they are seeking?
   Very few incidents repeat on multiple map pages. The average amount of time to watch until the desired information is viewed is approximately 60 to 150 seconds.

3. What is the average length of time that the program is watched?
   Not applicable. Not broadcast during evaluation. Unable to survey potential users.

4. How many people on average watch the program each day?
   Not applicable. Not broadcast during evaluation. Unable to survey potential users.

5. Are there any Bay Area households with cable television that do not receive the program?
   Not applicable. Not broadcast during evaluation. Unable to survey potential users.

4.2 Qualitative Outputs

Cost

1. Does the system need day-to-day maintenance or oversight? ☐ YES ☒ NO
2. Describe any maintenance that is required and the time required.

   Since this content is generated by a software program, it is virtually maintenance-free once it is operational.

Productivity

1. Evaluate the relevance and timeliness of the transit information that is shown.

   Transit information is not shown.

2. Is the system capable of providing alternate route information for transit or roadway incidents? ☐ YES ☒ NO

3. What type of manual operation is needed when information is broadcast in order to keep the information accurate and useful?

   None. The program would benefit from the ability for 511 control center employees to insert additional transit or traffic related bulletins. The system was originally intended to provide that feature and make it user-friendly.

4. Are the maps shown legible and informative? ☒ YES ☐ NO

5. Is the traffic camera footage shown as part of the program pertinent and beneficial?

   Not applicable. Video camera footage not included in TV511 feed.

6. Does TV511 provide improved access to information when compared to existing services available on the internet or via telephone?

   It is virtually the same information as that provided on 511.org or by calling 511. If a person does not have access to either of these resources, TV511 would improve access to this information.

How do these performance measures relate to Caltrans' 9 Performance Measures?

Caltrans' performance measures are used to assess the operations of multi-modal transportation systems in order to create a more accountable framework for decision making. The following table relates the project performance measures against the Caltrans performance measures.

	Caltrans 9 Performance Measures								
	Mobility/Accessibility/ Reliability	Productivity	System Preservation	Safety	Environmental Quality	Coordinated Transportation and Land Use	Economic Development	Return on Investment	Equity
Outputs Measured									
Accuracy	x								
Cost								X	
Reliability	x								
Productivity	x	X					X	X	X

4.3 Performance Factors

Interoperability and compatibility

The TV511 program includes incident information that is also available on the 511.org website or via telephone. The information feed comes from the 511 database, so it does not include any additional information that is not available on the 511.org website. As a result, there is a consistency between all of the traveler information that is being disseminated.

Scalability and Sensitivity

KMTP broadcast TV511 during the ITS World Congress (November 2005) and ceased broadcasting shortly afterwards. There is no current viewer base for the program. KMTP did not return queries during the evaluation period that measured the user base. Considering these factors, it is not possible to determine the following:

- **Demand for the provision of this service during the p.m. peak hour or for special events**
- **Opportunity by KMTP to expand the service to other times of day**
- **Impact on viewership by an increase in the regional area covered by 511**

Increasing the coverage area may negatively impact the viewers' ability to quickly obtain useful information if there are irrelevant maps that the viewer would need to view prior to receiving useful information. The increase in viewing time depends on the increase in size of the regional area and number of local maps that are shown in a single loop.

Staffing and Training

No day-to-day staff or specialized training would be required by the broadcast station staff. Installing the program onto a local computer took approximately 20 minutes after which the output for the computer is ready for display. The loop runs continuously until interrupted by staff.

Cost

TeleAtlas approximates a one-time installation cost between $10,000 and $25,000 per partner to cover initial set-up, equipment and configuration costs. The broadcast partner would need to obtain equipment (TV511 Television Server, internet communications equipment) in addition to the transmission equipment (which is assumed to already be available by the partner). Day-to-day staff needs would fall under maintenance of the computer and Internet connection.

According to TeleAtlas, the on-going cost of the program for the broadcast partner and TeleAtlas is approximately $200,000 per year to cover airtime, maintenance and profit for TeleAtlas. This money would be approximately split between the broadcast partner and TeleAtlas. If city cable channels were used (assuming that "airtime" on these channels is provided at no cost), the fee for TeleAtlas' provision of its service is about $10,000 per city per year, depending on the number of cities.

5. Evaluation Methodology

This section describes the process and procedure for conducting the evaluation of TeleAtlas TV511.

Performance measures were evaluated during a real-time evaluation of the TV511 broadcast during peak periods and obtaining program characteristics from TeleAtlas, KMTP and viewers.

Real-Time Evaluation (Accuracy & Reliability)

- **Compare TV511 displays with the following information to determine delay and accuracy of broadcast information:**
  - **511 speed data**
  - **Real-time traffic cameras**
  - **Transit data**

- **Observe TV511 programs to evaluate:**
  - **Accuracy of information**
  - **Transmission errors and error messages**
  - **Length of viewing time needed to obtain information**
  - **Depth and relevance of information**
  - **Quality of displays and commentary**

Obtain Broadcast Program Characteristics

- **Communicate with Tele Atlas to obtain the following information:**
  - **Cost of production, equipment, airtime and maintenance**
  - **Staffing requirements**

- **Communicate with KMTP to obtain the following information:**
  - **Number of viewers**
  - **Scheduling restrictions**
  - **Demand for expanded coverage**

- **Obtain feedback from viewers on the following items:**
  - **Viewing time required to obtain relevant information**
  - **Average viewing time**
  - **Relevance of information**
  - **Quality of displays and commentary**
  - **Demand for expanded coverage**

6. Evaluation Results

Observations of the TV511 system were conducted during the following periods:

- **April 12, 2006 PM Peak**
- **April 13, 2006 AM Peak**
- **April 27, 2006 PM Peak**
- **April 28, 2006 Mid-day**

Accuracy

The program's technology achieves its goal of allowing users to access 511 traveler information via their television sets. Incidents are clearly indicated with icons on the regional freeway maps. The four focused coverage maps effectively cover the entire Bay Area. The program is a reasonable time length, such that a person would probably not mind watching an entire cycle to view the relevant information. The program displays text and has accurate accompanying audio for each incident, describing the location, type and effect on the roadway of each incident. The only issue detected with the audio is that zeroes in the time of incident are not included. For example, "2:07" was read as "2:7".

In a couple of instances, incidents were repeated on multiple map views. One incident on Interstate 680 was repeated on three different maps on the same cycle. This is beneficial if a person was only paying attention to announcements for a specific map, but it has the downside of lengthening the program with repeat information.

The TV511 program references a 511 MTC database to obtain its incident information. Therefore, the accuracy of TV511 depends on the accuracy of the 511 database. There were no major issues with the accuracy of the incident information. All incidents were reported correctly when compared to the 511.org website and the traffic incident information page at SFgate.com. Incidents were also updated continuously, both as conditions changed and as new incidents developed. There was a delay in the broadcasting of approximately 30% of the incidents, usually only a matter of a few minutes. Of the incidents for which there was some delay in being posted, that delay averaged 24 minutes. The delay was also noticed in the traffic incident output on SFgate.com, which may use the same traffic data output from MTC as TV511. For cases where information was late in being displayed by TV511, TeleAtlas hypothesized that its database or the MTC database it was using was not entirely synchronized with the database supplying the 511.org website or SFgate.com.

For one incident in the mid-day evaluation period, the location of the incident and time of incident was read but no incident type or roadway closure was included. The text at the bottom of the screen was "See script." A check of the 511.org website at that time yielded the same result. Therefore, the error was with the 511 database, not with TV511.

Some traffic information displayed on 511.org and SFgate.com was not displayed by TV511 at any point during the program. During each of the three peak periods evaluated, two long-term construction-related road closures were not included on TV511 but were shown on 511.org. In addition, an event at the Cow Palace and two severe traffic alerts/road closures were not displayed by the system, but were shown on 511.org.

Reliability

There were no reliability issues observed during the evaluation, beyond the previously discussed delay in displaying some of the incidents. For the evaluation, the internet feed of the program was used. During no point did the feed discontinue or stall. Of course the reliability of the system is dependent on the broadcasting station as well. At the time of the evaluation, the broadcast partner, KMTP, had chosen to broadcast other programming, highlighting a significant accessibility concern for the TV511 program. Viewers cannot access the TV511 program if there is no sponsorship, or the broadcasting station chooses to air other programming,

Broadcast Program Characteristics

The program was aired on broadcast television during the 2005 ITS World Congress. Immediately following the conclusion of the World Congress, it was replaced by other programming on KMTP. KMTP could not be reached to discuss the TV511 program. Information regarding the number of viewers, scheduling restrictions and demand for expanded coverage could not be obtained. According to TeleAtlas, KMTP received numerous complaints when its other programming was temporarily suspended to show the TV511 broadcast.

Since the program is not being broadcast, feedback from viewers could not be obtained.

From an operational standpoint, the system is simple to initialize and operate. A computer at the broadcast station with an internet connection to the TV511 server is required. TeleAtlas provides an installation CD for placing the TV511 program on the computer and configuring the connection to the TV511 server. Installing the program took approximately 20 minutes, after which the output for the computer is ready for display on a computer monitor or to be broadcast.

No day-to-day maintenance is required of the broadcast partner outside of maintaining the computer and internet connection. The maintenance of the TeleAtlas server and connection with 511 is borne by TeleAtlas.

The TeleAtlas server allows easy expansion to numerous broadcast partners.

TeleAtlas suggested using city cable channels to attempt to reach viewers with the program. A similar approach is currently in use in Phoenix, AZ and may be utilized in St. Louis, MO.

The difficulty of finding a broadcast partner is a significant downside to this technology. If no funding sponsor is found, the broadcast partner is likely to replace TV511 with paid programming or more popular programming. Sponsorship would negate this concern.

Other observations

There are a few significant features that are missing from the program. Most noteworthy, is that speed information is not displayed, only incident information. While this program indicates whether an incident is present and the user can insinuate a slowdown will occur from that, the user is unable to determine how congested the freeways are at any point on the system or their expected travel time. This limits the overall value for the viewer. Additionally, the program does not display several types of congestion generators, such as general slowdowns, special events, construction activities, and landslides. Additionally, transit information is notably absent from the program. For example, the SFgate website listed a 15 to 20-minute delay on two BART routes during one of the evaluation periods, but that information was not broadcast by TV511.

It would be beneficial for the service to allow bulletins to be posted remotely by 511 staff, which would require some day-to-day effort by 511 staff to enter the messages. This would require minor changes to the software program. If these messages are sent directly to the TV511 server, they would not be included in the 511 database since the communications between the 511 database and the TV511 serverServer are one-way only.

According to TeleAtlas, the TV511 program could be improved relatively easily to include all the features mentioned above. They were not included in the evaluated version due to budget and time constraints.

7. Recommendation to Caltrans

PROS	CONS
Provides enhanced incident information without the use of computer/ internet access	Requires sponsorship for broadcast
Displays incident information effectively with coordinated voice and text displays	Does not include transit, travel time, speed data, or slowdown incidents
Information is nearly identical to what is posted on 511.org and SFgate.com	Cannot provide user-customized information like the 511.org website and phone service
Quickly cycles through all Bay Area incidents (every 3-5 minutes)	Viewer required to watch non-relevant information to obtain desired information
Updates incident information as it is received	Some delay incurred in displaying a percentage of incidents
Simple initialization with little to no maintenance	
Potential for revenue generation through sponsorship	

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ITS Pilot Project Demonstration

ENCOM Wireless Evaluation

Prepared for
Caltrans

December 2006
FINAL

Prepared By
Kimley-Horn and
Associates

ITS Pilot Project Evaluation

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Evaluation Summary

Vendor/Project – ENCOM Wireless Data Solutions

ENCOM wireless communication units (radio modems) establish a wireless communication link between various traffic monitoring and control systems. The objective of this technology is to provide a cost-effective alternative to the hardwire cable communications in the transportation engineering industry.

Delivery: Does demonstration satisfy Vendor's stated objectives for Caltrans?

Installment is less expensive than deployment of hardwire communication

☒ YES ☐ NO

Depending on the length of conduit required for hardwire communication and the conduit installation cost, installing an ENCOM radio system may be less expensive than deploying hardwire communication.

Installment is less disruptive than deployment of hardwire communication

☒ YES ☐ NO

Using a wireless systems can eliminate the need to install long stretches of conduit (either along on in the roadway) that may result in traffic disruption. There would be less disruption to traffic as long as the cabinets on which ENCOM devices are being installed are outside the travel way.

Maximizes flexibility for new deployment locations ☒ YES ☐ NO

ENCOM radios could be used to establish communications with new locations (with sufficient line of sight) in less time than if new conduit needed to be installed. ENCOM radios could also be used for temporary purposes at existing locations (for instance, construction zones where temporarily disconnection of hardwire communication might be required).

Enables a single TMS/RMS controller to serve multiple detection locations

☐ YES ☐ NO ☒ NOT VERIFIED

ENCOM did not establish this for evaluation.

Useful when installed hardwire communications fail ☒ YES ☐ NO

In a situation where hardwire communications fail, ENCOM radios could be used to quickly reestablish communications if sufficient line of sight exists while the hardwire communications are being diagnosed.

Key Observations

Installation of an ENCOM wireless communications link was observed to be done quickly and to provide a communications link in place of a hardwire connection. However, the observed communications rate with the ENCOM link in place was lower than when the hardwire link was in place. It appears that the communications rate of the ENCOM wireless connection was between 75% and 80% compared to about 99% with the hardwire connection. ENCOM was not given the opportunity to additionally troubleshoot or make adjustments to these deployments.

The vendor claims that the communications rate experienced with a wireless connection should be the same as with a hardwire connection. However, factors such as poor line of sight, poor antenna alignment, bad radio path or improper installation of drivers could reduce the actual communications rate. Addressing these issues could require more troubleshooting and equipment configuration than when using hardwire connections.

In general, an ENCOM wireless connection can be installed more quickly than a traditional hardwire connection and with less disruption to traffic. While the radio may be more expensive than a traditional copper FSK modem, utilizing an ENCOM wireless radio may be more cost effective depending on the length of conduit and cable that is being replaced. Assuming an installation cost of $50 per foot for conduit, the ENCOM wireless solution could be cost effective at 130 feet, and perhaps even shorter if one considered a reduced traffic control cost.

Recommendation to Caltrans

PROS	CONS
Does not require trenching or directional drilling for installation of conduit; avoids traffic disruption due to conduit installation	Requires near line of sight between antennas free of obstructions due to buildings and vegetation.
May be less expensive in situations where conduit installation is expensive or difficult to install.	Additional ongoing troubleshooting/ equipment configuration may be required over hardwire connections.
Can be installed more quickly than when conduit installation is required; useful as a temporary solution when hardwire communication cables are broken or are removed during construction.	Increased maintenance to trim vegetation could be needed to maintain line of sight.
Uses RS232 and FSK protocols commonly used by traffic controllers.	Line of sight could be blocked by future buildings.
Utilizes license-free, low-power frequencies for communications.	Antennas might attract unwanted attention to cabinets; issues related to damage and theft of equipment might arise.
Can handle point-to-point and point-to-multipoint configurations.	Drilling holes in the cabinet walls could be required for antenna cables; these holes are additional location for dirt, dust and moisture to enter cabinet. If ENCOM equipment is relocated to another location, these holes would need to be sealed.

Evaluation Details

1. Delivery

Vendor's Stated Objective In Caltrans contract:

- ❒ *Eliminates the need for long lead-in cables*
- ❒ *Cost-effective wireless communication system*
- ❒ *Less disruptive than deployment of "hardwire" communications*
- ❒ *Maximizes deployment location flexibility*
- ❒ *Enable a single TMS/RMS controller serve multiple detection locations*
- ❒ *Designed to have extremely low signal latency*
- ❒ *Very simple installation process*

Additional Assertions:

- ❒ *Equipment is maintenance free*
- ❒ *Robust design and can withstand extremely high/low temperatures (-40°C to 80°C)*

2. Project Specifics

Deployment Locations and Dates	Evaluation Locations and Dates *Include weather conditions*
1. **Valley Blvd On Ramp at I-10 EB, City of El Monte, California (Caltrans LDS #715158):** *Installation: 10/17/2005* *Approx. operational date: 11/01/2005* 2. **Baldwin Ave On Ramp at I-10 EB, City of El Monte, California (Caltrans LDS #715286):** *Installation: 10/17/2005* *Approx. operational date: 11/01/2005* 3. **Madre St Ramps at I-210 EB, City of Pasadena, California (Caltrans LDS #715484):** *Installation: 6/29/2006* *Approx. operational date: 6/29/2006*	Evaluation locations are same as deployment locations: 1. **Valley Blvd On-ramp:** *Before* – 08/25/2005 to 09/01/2005;* *After* – 11/20/2005 to 11/27/2005* 2. **Baldwin Ave On-ramp:** *Before* – No data (no communications in place);* *After* – 01/10/2006 to 01/17/2006* 3. **Madre St Ramps:** *Before* – 04/20/2006 to 04/27/2006;* *After* - 08/25/2006 to 09/01/2006* **Weather Data not available**

**"Before" date indicates communication on 4-pair copper interconnect. "After" date indicates communication on ENCOM wireless equipment*

Information used for the evaluation included field observation of equipment installation, field investigation of installed equipment, collecting and checking vendor-supplied information, and interviews with Caltrans technical and engineering staff. Performance data consisted of comparing the communications rate (up-time) between the existing hardwire copper connections and with the ENCOM wireless in place. (Accuracy of the data transmission was originally included in the evaluation plan, but was not pursued because the needed information for comparison was not readily available.)

3. Technology

3.1 Technology or System Description

ENCOM wireless data modems provide wireless communication between various traffic monitoring and control systems, eliminating the need for hardwire communication between them. ENCOM products use license free, frequency hopping spread spectrum technology (FHSS) and the deployment locations in this evaluation utilized ENCOM Model 5100 (rack mounted and shelf mounted) and Model 5200 equipment (located in demarcation cabinets). Specification sheets for ENCOM equipment installed for this evaluation are located in Appendix A.

ENCOM wireless devices were installed at 3 separate locations as part of the Pilot Project. Two of these applications are similar. These two locations would replace the existing hardwire copper connection with the ENCOM wireless connection between the ramp metering controller and the telephone demarcation cabinet. (Caltrans TMC polls data using a leased telephone line from the demarcation cabinet.) The third application would replace the existing hardwire copper connection with the ENCOM wireless connection between two ramp metering controllers (on-ramp and off-ramp). Communication network details of each deployment location are described below and field photos of the deployments are shown in Appendix B.

Valley Boulevard/I-10 (eastbound) on-ramp and Baldwin Avenue/I-10 (eastbound) on-ramps

Figure 1 and Figure 2 illustrate the communication details for the Valley Boulevard/I-10 (eastbound) on-ramp and Baldwin Avenue/I-10 (eastbound) on-ramp application. These applications connect a Model 170 controller with a demarcation cabinet. Caltrans TMC is connected to the demarcation cabinet over a telephone line and polls the location every 30 seconds. Prior to the evaluation, the on-ramp Model 170 controller at the Valley Boulevard location communicated with the existing telephone (TELCO) demarcation cabinet via a 4-pair copper interconnect cable. This connection was replaced with ENCOM Model 5100 wireless radios at the telephone demarcation cabinet and the controller cabinet during the evaluation. (There was no existing communication for the Baldwin Avenue location.)

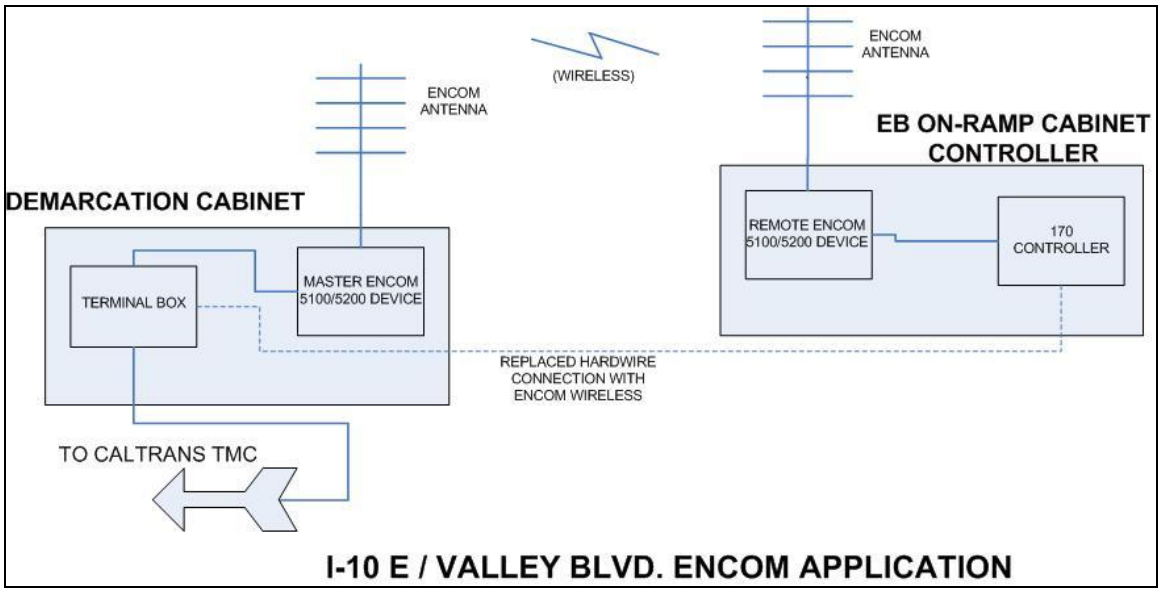

Figure 1: Valley On-Ramp at I-10 E ENCOM Application

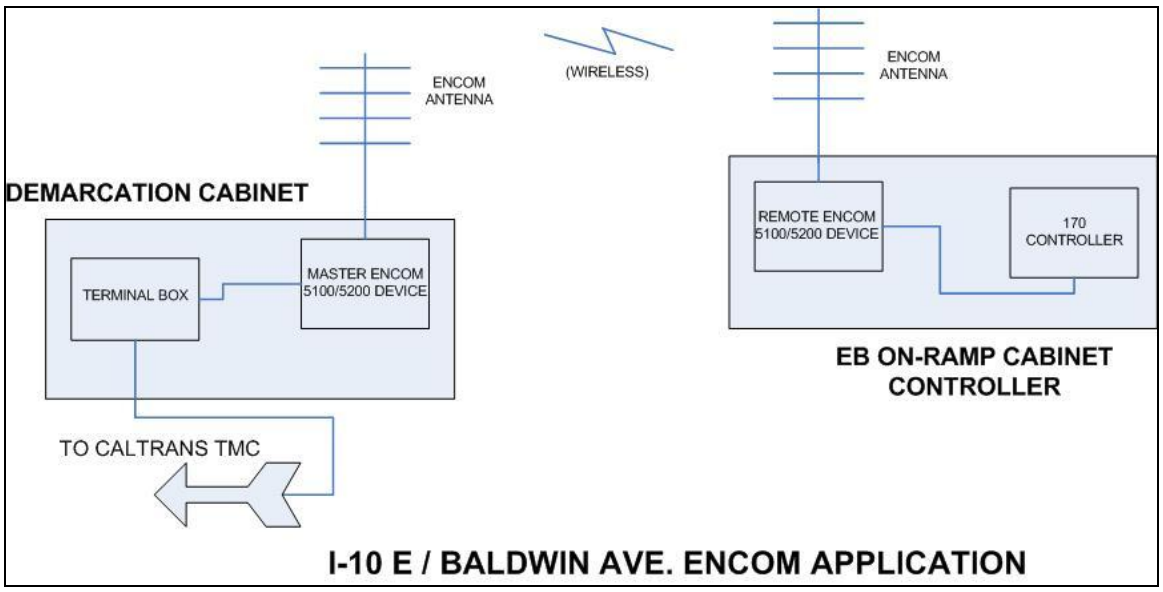

Figure 2: Baldwin On-Ramp at I-10 E ENCOM Application

Madre Street/I-210 (eastbound) location

Figure 3 illustrates the communication details for the Madre Street /I-210 (eastbound) application. For this application, the hardwire connection between two data bridges was replaced by a wireless connection. The existing communications configuration has the

on-ramp 170 controller communicating with the off-ramp Traffic Monitoring Station (170 controller) via a 4-pair copper interconnect using data bridges at both locations. The data bridge at the off-ramp location connects the controller and the main trunk line (50 pair copper line) via a 6-pair #22 connection. Caltrans TMC is connected to the main trunk line and polls the location every 30 seconds. For the evaluation, Model 5100-S Radio was installed at the off-ramp (Master) location and Model 5100-R Radio was installed at the on-ramp (Remote) location.

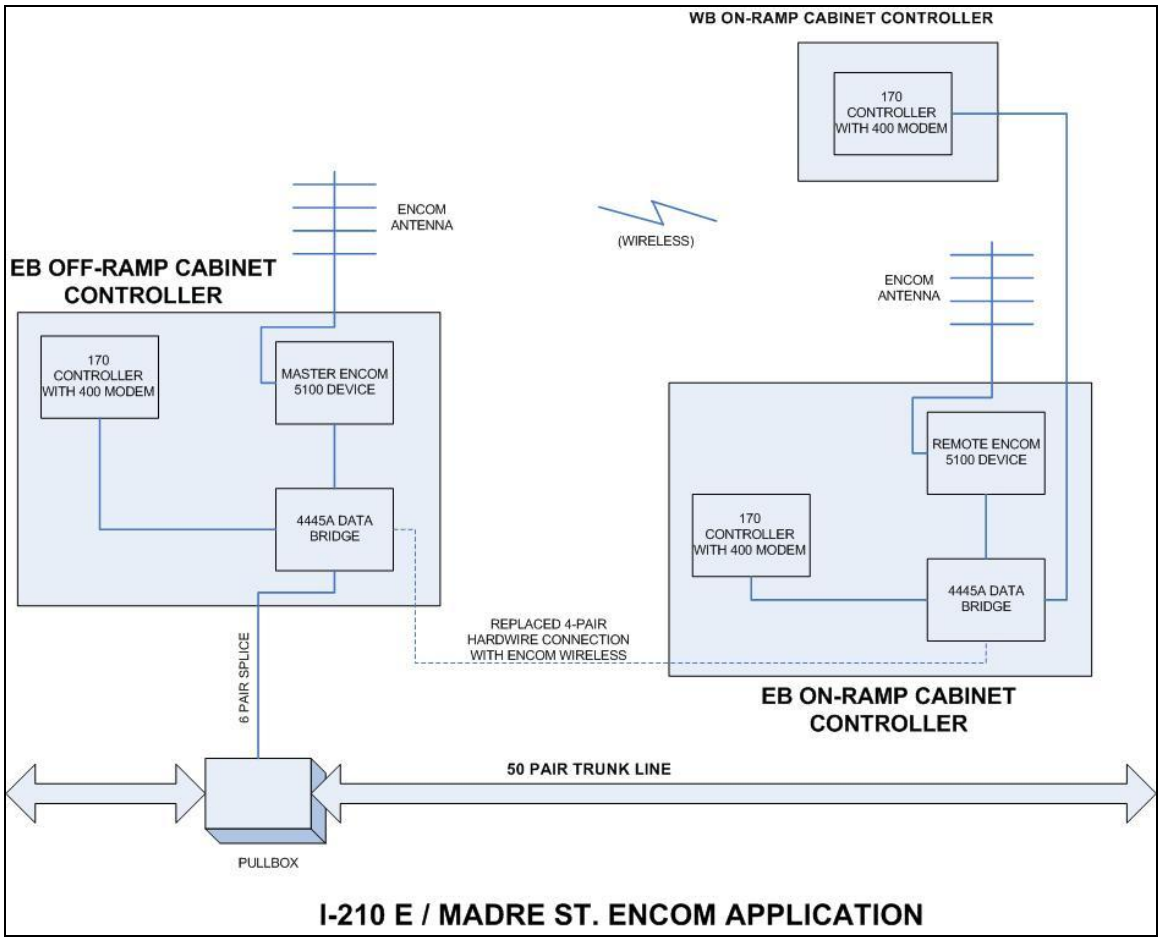

Figure 3: Madre Street Ramps at I-210 E ENCOM Application

Typical Installation Procedure

As per ENCOM, the equipment installation procedure typically involves the following steps:

1. Side-mounting the Yagi-antenna on the traffic controller/demarcation cabinet using brackets to hold it to the side.
2. Bringing the antenna cable into the cabinet (by drilling a hole on top of the cabinet) to connect to ENCOM 5100 series modem which is rack-mounted inside the cabinet. The antenna cable is routed through a surge protector (installed

inside the cabinet) before connecting to the ENCOM modem. The antenna cable connects to the modem through a reducer.

3. The modem is connected to a bridge behind the controller, which serves as the connection point between the two cabinet controllers (via a 4-pair copper cable).
4. ENCOM equipment inside the cabinet draws power from the 170 controller. The Vendor claims that typical power consumption of an ENCOM 5100 device is less than 100mA (standby) and less than 125mA (100mW TX).

3.2 Previous Evaluations (including vendor's own) and/or Similar Technology Deployments

This equipment is currently being deployed in several areas in North America. It is not known if these deployments have been evaluated independently or by the agencies that are using them so it is not possible to give a summary of performance in other deployments.

3.3 Cost

The equipment list price for the Model 5200 radio is $1,350 and the equipment list price for the Model 5100 radio is $1,790. This does not include miscellaneous mounting and cabling or installation costs. With an assumed labor rate of $100 per hour, the labor installation cost is approximately $500 per site ($1000 for a two point system).

4. Performance Measures

Performance measures are defined here for this project and are divided into different categories for evaluation and discussion: Quantitative, Qualitative, and Other Performance Factors.

Definition of Performance Measures

The ENCOM wireless data modems provide wireless links for data communication between traffic monitoring devices such as inductive loops and traffic controllers.

4.1 Quantitative Outputs

Accuracy

1. *Does the presence of vegetation/high-rise buildings affect the signal strength/block the transmission signal?* ☒ YES ☐ NO

   During the installation at Madre St/I-210 E, there were line of sight issues due to the obstruction of freeway infrastructure and presence of vegetation. Other locations were not considered for ENCOM application due to possible line of sight issues.

2. *What is the approximate distance beyond which the signal strength shows a decrease in accuracy?*

   The Vendor claims that ENCOM equipment can communicate up to 20 miles distance with proper line of sight.

3. *Does the curvature (geometry) of the roadway affect the transmitted signal?*

   ☐ YES ☒ NO

   The geometry of the roadway does not affect the transmitted signal as long as there is line of sight.

4. *Are measurements affected by low light conditions?* ☐ YES ☒ NO

   Nighttime (low light) conditions did not appear to have an impact on measurements.

5. *Are measurements affected by low visibility/cloudy/foggy conditions*?

   ☐ YES ☐ NO ☒ NOT EVALUATED

   Weather information was not available, so it was not possible to evaluate the impact of low visibility/ cloudy/ foggy conditions.

6. *What is the signal latency of the wireless equipment compared to fiber or copper?*

   The vendor claims that the end-to-end signal latency of ENCOM wireless equipment is not more that 8 milliseconds. For a rough comparison, the signal latency of a typical Ethernet (copper) connection is 0.3 milliseconds and 0.2 milliseconds for fiber (assuming a 20 mile network).

7. *Is the communication delay time caused due to signal latency below the system latency constraints?* ☐ YES ☐ NO ☒ NOT EVALUATED

   Information on system latency constraints were not available.

8. *Does the presence of local RF interference affect the accuracy of the signal transmission?* ☐ YES ☒ NO

   Vendor claims that by utilizing the tools included with the ENCOM devices, the accuracy of the signal transmission should match the accuracy of hardwire connection. These tools include built-in spectrum analyzer to identify sources of interference and a remote diagnostic tool to optimize the radio path.

Cost

1. *Are any other additional components necessary for the equipment to function?* ☒ YES ☐ NO

   Other additional components needed for each radio includes a Yagi antenna (and mounting brackets), an antenna pole, and miscellaneous cabling (e.g., antenna and communication), surge protector and connectors. The estimated costs for this equipment is $600.

2. *What is the length and cost of installation?*

   As per the vendor, the complete installation and testing/configuration for a location that has clear line of sight could be performed between 75 to 90 minutes with 2 personnel. Installation at one location was observed to take about 2½ hours with 2 trained persons. The estimated cost of installation (assuming a labor rate of $100 per hour) is $500. No special training would be anticipated for typical Caltrans maintenance crew to install or configure Encom equipment (modem and antenna).

3. *How many loop detection stations can be linked to one TMS/RMS controller without introducing significant latency?*

   Vendor claims that up to 255 loop detection stations could be linked to a single ENCOM access point. This was not verified as part of this evaluation. The Valley Boulevard and Baldwin Avenue locations connected one controller to one demarcation cabinet. The Madre location connected a Model 170 controller with a remote data bridge with two Model 170 controllers connected to it.

4. *Are there any recurring costs for training/maintenance services?* ☐ YES ☒ NO

   The vendor claims that the operation is maintenance free. During the Pilot Project period, there was no record of equipment maintenance requests or services. Since the evaluation was short, it was not possible to evaluate if periodic maintenance is needed to sustain performance.

5. *Is this equipment useful in areas where there is already existing hardwire communication along the roadway?* ☐ YES ☒ NO

   ENCOM radios could be useful to communicate with new locations given sufficient line of sight without expanding the existing hardwire communications. ENCOM radios could also be used for temporary purposes at existing locations (for instance, construction zones where temporarily disconnection of hardwire communication might be required). ENCOM radios might not be useful at locations where there are existing communication

systems unless the controlling agency requires additional/alternative communication needs.

6. *Does the equipment require frequent trimming/maintenance of trees/vegetation along the line of sight to maintain necessary line of sight?* ☒ YES ☐ NO

   If there is vegetation in the line of sight, regular trimming would be required to maintain sufficient line of sight.

7. *What are the costs associated with power requirements to operate the equipment?*

   ENCOM equipment inside the cabinet draws power from the detector rack via the edge connector. Vendor claims that ENCOM equipment typically requires less than 100mA in standby mode, and less than 125mA when transmitting at 100mW.

8. *Describe the cost savings in comparison to hardwire communications.*

   Figure 4 illustrates the cost of a point-to-point ENCOM Model 5100/5200 system with the cost of conduit installation for various lengths of conduit and cable ($50 per foot, $60 per foot, $70 per foot of conduit). In this figure, the breakeven distance occurs at 130 feet assuming $25 per feet of conduit. The breakeven distance assuming $60 per feet and $70 per feet of conduit is approximately 108 feet and 94 feet, respectively. Beyond this distance, given sufficient line of sight and data transmission efficiency of ENCOM communication system, the ENCOM equipment would be cheaper than installing the conduit and cabling needed to connect the two points.

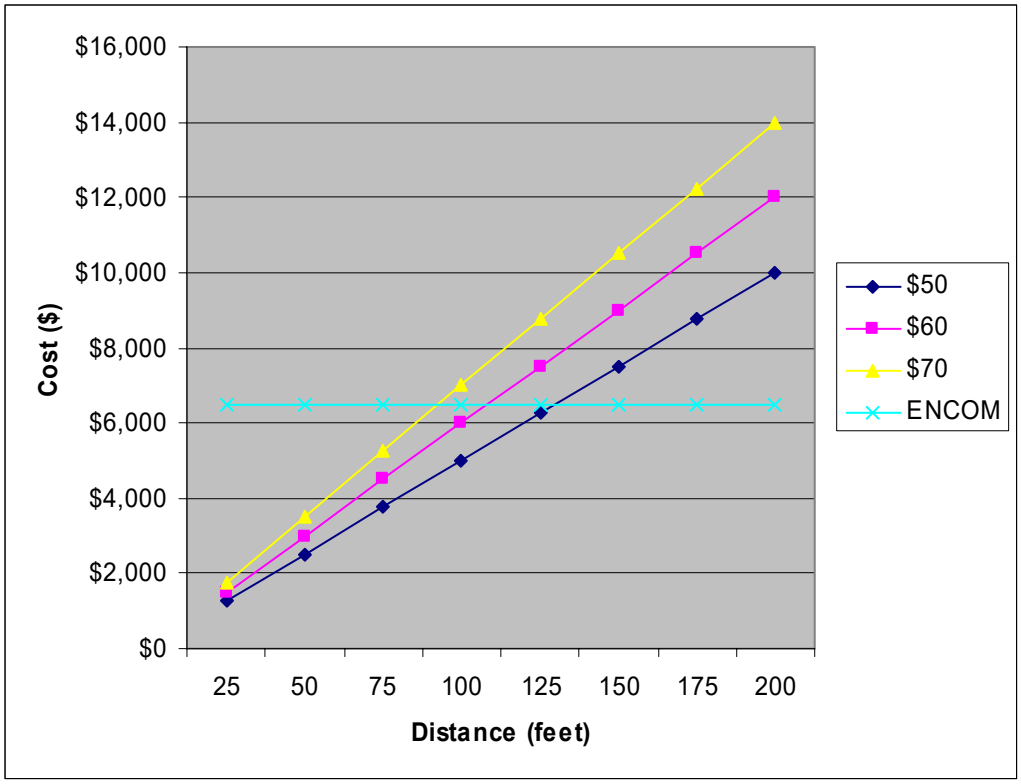

Figure 4: Cost Comparison: ENCOM and HARDWIRE COMMUNICATION

Reliability

1. *Was traffic disrupted during installation?* ☐ YES ☒ NO

   Vendor claims that there is no disruption to traffic during installation. There was no traffic disruption observed during the Madre Street installation.

2. *If yes, what was the length of time of the disruption and/or length of disruption?*

   Not Applicable. See Question 1 (above).

3. *Did the units fail during the evaluation period?* ☐ YES ☒ NO

   None of the ENCOM units failed during the evaluation period.

4. *How many times did the communications fail to transmit data?*

   During the "after" evaluation period (one week), the communications rate was 73.9% for the Valley Boulevard location, 49.6% for the Baldwin Avenue location, and 72.9% for the Madre Street location. See Section 6 (Evaluation Results) for additional information. It is unclear if this indicates that the data was not transmitted or if it was not received (due to calibration and configuration issues.)

5. *What is the maximum bandwidth at which the device operates?*

   Vendor claims up to 115kbps sustained data throughput is capable with the Model 5100/5200 radios. This claim was not verified. Information regarding the bandwidths used for the deployment applications was not available.

6. *What was the average bandwidth in a 24-hour period?*

   Average and minimum bandwidth information was not available.

7. *What was the deviation from that average bandwidth?*

   See Question 6 (above).

8. *What was the lowest measured bandwidth?*

   See Question 6 (above).

9. *Did any devices need to be replaced or repaired during the evaluation? If so, how many and what was the amount of time before the replacement or repair and the cost of the replacement/repair?*

   The field/installation crew (Crosstown Electric) noticed that the communication line to the telephone demarcation cabinet was disconnected (cause unknown) at the Baldwin Avenue location. It was fixed between April 24th and April 28th, 2006. However, this loss of communication is not attributed to ENCOM devices.

10. *Is the device designed to operate at extreme (hot or cold) temperatures (robustness)?* ☒ YES ☐ NO

    Vendor claims that the equipment works in the temperature range of -40˚C to +80˚C (-40˚F to 176˚F).

11. *Once configured and operational, how often does the equipment need to be reconfigured or maintained to provide acceptable service?*

    Due to the short duration of the evaluation period, there was no reconfiguration or maintenance that was performed during the course of the pilot project. As previously mentioned, vegetation trimming and possible antenna alignment maintenance may be required to maintain operability.

Productivity

1. *What is the lag time between when the time data is measured and when it is received at the monitoring station?*
   Information is not available.

2. *Does the equipment use/need any special software?* ☒ YES ☐ NO
   Vendor claims that ENCOM equipment is completely configurable with Windows™ based ControlPAK™ Software (included). Further, the Vendor claims that for standard traffic interconnect applications, a wide range of pre-built and pre-tested application files are included, allowing "plug-and-play" setup for specific controllers and most major controller manufacturer's products and third party applications are represented.

4.2 Qualitative Outputs

Accuracy

1. *How does the distance between devices impact the accuracy of the device?*
   According to the vendor, the accuracy of the device should not be impacted as long as there is sufficient signal strength. Vendor claims range of 20 miles (if line of sight is sufficient). The distances between antennas for these deployment locations was approximately 700-800 feet.

2. *Is the system line of sight specific?* ☒ YES ☐ NO

Compatibility/Interoperability

1. *Is the equipment compatible with different antennas?* ☒ YES ☐ NO
   The vendor claims that the equipment is compatible with Yagi and Omni antennas. All the three applications (locations) have Yagi antennas installed.

2. *Can the equipment operate with different traffic controllers available in the industry and/or used by Caltrans?* ☒ YES ☐ NO

   The vendor claims that ENCOM devices have drivers (application files) for most major controller manufacturer's products. All the three applications (locations) in this evaluation have 170 controllers.

3. *Can the equipment be used for other freeway monitoring applications (e.g. volume, queue detection, video)?* ☒ YES ☐ NO

   ENCOM equipment could be used for applications that require up to 115kbps bandwidth (such as data transmission). Video applications might require higher bandwidth.

Reliability

1. *How does inclement weather affect the performance of the equipment? Describe the type of weather and any effect on the system's range, accuracy and communications capabilities:*

   Weather information not available. Vendor claims that ENCOM devices can function in the temperature range of -40˚C to +80˚C (-40˚F to 176˚F). Like most wireless applications, foggy and cloudy weather conditions might disrupt the wireless communication.

2. Can Caltrans maintain and/or install the device? ☒ YES ☐ NO

3. What is the level of encryption?

   Vendor claims that the wireless communication has 32-bit encryption.

Productivity

1. Does device improve Caltrans' ability to gather/process/disseminate data more efficiently? ☒ YES ☐ NO

   ENCOM applications could be used for temporary purposes at existing locations (for instance, construction zones where it might be required to temporarily disconnect existing hardwire communication) or locations where it would be infeasible to install conduit. Installation of an ENCOM system would be expected to be quicker than a hardwire installation.

2. How do these performance measures relate to Caltrans' 9 Performance Measures?

Caltrans' performance measures are used to assess the operations of multi-modal transportation systems in order to create a more accountable framework for decision making. The following table relates the project performance measures against the Caltrans performance measures.

	Caltrans 9 Performance Measures								
	Mobility/Accessibility/ Reliability	Productivity	System Preservation	Safety	Environmental Quality	Coordinated Transportation and Land Use	Economic Development	Return on Investment	Equity
Outputs Measured									
Accuracy	✓								
Cost	✓		✓					✓	
Compatibility/Interoperability			✓				✓	✓	
Reliability	✓	✓							
Productivity	✓	✓					✓	✓	

4.3 Performance Factors

Interoperability and compatibility

The Model 5100 and Model 5200 ENCOM equipment are serial radios that utilize serial communication protocol common to the traffic signal control industry. The Model 5100 radio supports both RS-232 and FSK protocols, while the Model 5200 radio supports only the RS-232 protocol. This support should allow the system to easily integrate with other traffic signal control devices and other communication systems.

Line of sight issues

The ENCOM radios require line of sight between antennas for satisfactory operation. This may require a sight-and-path survey to be conducted prior to choosing to install ENCOM radios instead of traditional hardwire connections. Some additional testing may be required when placing the antennas and configuring the radios to maximize to radio path. For the Madre Street location, the installation technicians performed a quick survey to confirm sufficient line of sight. Caltrans District 7 staff and the installation technicians also considered some other locations to install ENCOM devices prior to choosing this location. However, those locations were discarded due to insufficient line of sight.

Interference with other wireless operations and emergency service operations

The Model 5100 and Model 5200 radios operate on the 900 MHz and 2.4 GHz unlicensed bands with a maximum output of 1 watt. Due to these restrictions, their operation is unlikely to interfere with emergency service operations that typically operate on a licensed frequency.

However, ENCOM radios face a chance of interference with other users since there are no restrictions for others to operate on the 900 MHz and 2.4 GHz bands. ENCOM radios come with various tools to minimize the chance of interference, including built-in spectrum analyzer (to identify sources of interference) and a remote diagnostic tool to optimize the radio path. These tools require some training.

System Configuration and Scalability

Vendor claims that it is possible to utilize these devices in Point to Point, Point to Multipoint, Multipoint to Point, and Multipoint to Multipoint system configurations. Since one ENCOM master device can connect and receive data from multiple remote ENCOM devices, this set-up can reduce costs compared to installing each pair of Master-Remote configuration.

5. Evaluation Methodology

This section describes how the performance measures described above were evaluated.

- Communicate with vendor regarding:
  - ENCOM equipment capabilities
  - ENCOM equipment interoperability and compatibility
  - Installation procedures and requirements
  - Testing procedures and requirements (including identifying probable sources for failure and signal loss)
  - ENCOM equipment costs
  - ENCOM equipment maintenance/operational requirements
  - System restrictions

- Observe installation of ENCOM equipment at test locations.

- Examine data received by Caltrans to determine the following for the "before" and "after" condition:
  - Number of readings
  - Number of weak data transmissions
  - Number of failed units/duration of failure
  - Bandwidth levels
  - Latency time of data transmission
  - Accuracy of data transmitted by ENCOM wireless systems

- Communicate with Caltrans to determine:
  - Integration and data transmission capabilities of ENCOM wireless systems compared with hardwire communication systems
  - Benefit gained from ENCOM wireless equipment

6. Evaluation Results

Installation Observations

Installation of ENCOM equipment at the Valley Boulevard and Baldwin Avenue locations was not observed. Installation of ENCOM equipment at the Madre Street location was observed.

Before/ After Comparison

In order to assess the impacts of the change in communications rate between the type of connection (hardwire or ENCOM wireless), communications rate data was gathered for a continuous one week of two months before and two monts after the ENCOM operational date. It is assumed that any differences observed in the communications rate would be due solely to the type of connection. Data was obtained from Performance Management System (PeMS) website maintained by University of California, Berkeley in order to assess the performance of the ENCOM wireless devices. The dates of the observation and the before/after periods are listed in Section 2. Project Specifics (above). The following figures and tables present the analysis results for the three ENCOM locations.

Valley Boulevard Location

As shown in Figure 4 and Figure 5, the communications rate (percentage of expected samples) in the "before" period (copper interconnect) ranged between 99.5% and 99.9% with an average of 99.7%. During the "after" period (with ENCOM wireless communication in place), the communications rate ranged between 73.0 and 74.5% with an average of 73.7%.

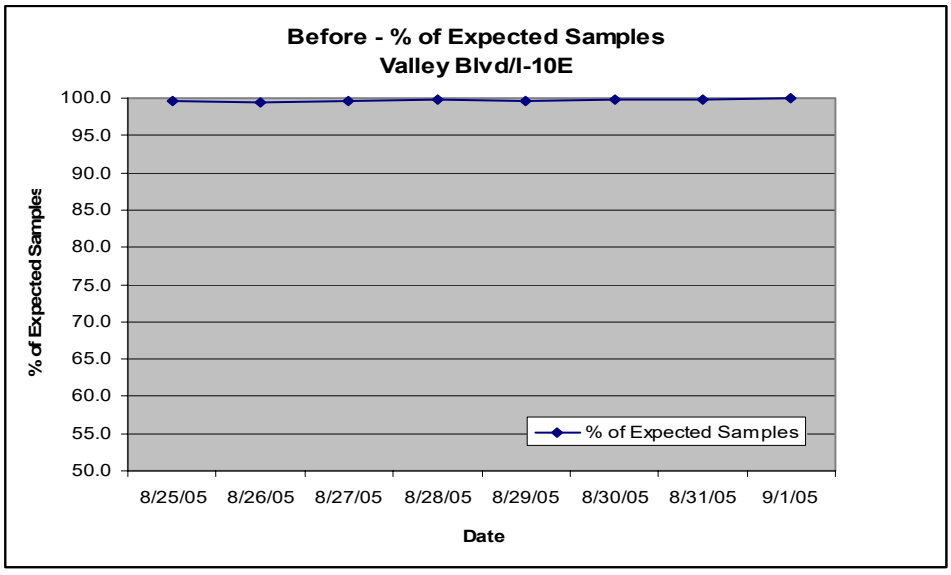

Figure 4: Valley Blvd/I-10E – Before Scenario Results

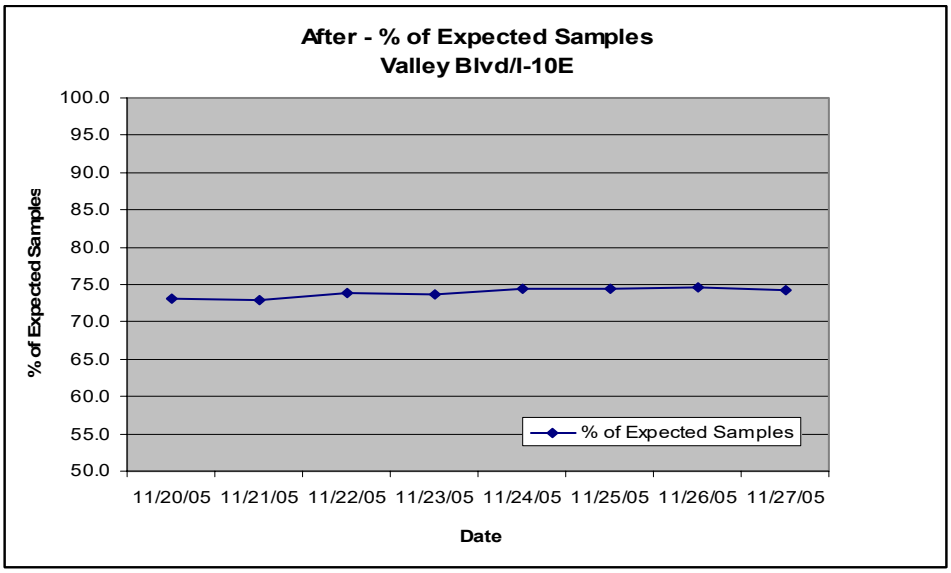

Figure 5: Valley Blvd/I-10 E – After Scenario Results

Table 1: Valley Blvd Before and After Daily Communications Rate

Valley Blvd Before		Valley Blvd After	
Date	**Communications Rate**	**Date**	**Communications Rate**
8/25/2005	99.7	11/20/2005	73.1
8/26/2005	99.5	11/21/2005	73.0
8/27/2005	99.5	11/22/2005	73.8
8/28/2005	99.8	11/23/2005	73.6
8/29/2005	99.6	11/24/2005	74.4
8/30/2005	99.8	11/25/2005	74.4
8/31/2005	99.8	11/26/2005	74.5
9/1/2005	99.9	11/27/2005	74.3
Average	**99.7**		**73.9**

Source: PeMS at http://pems.eecs.berkeley.edu/

Baldwin Avenue Location

The Baldwin Avenue location did not have communications prior to the installation of the ENCOM radios. Therefore, there is no data available for "Before" analysis. As shown in Figure 6, the communications rate in the "after" period ranged between 0% and 82.1%. There were two days where no samples were received, after which the radio recovered (apparently with no intervention by Caltrans or ENCOM staff). Including these two days, the average communications rate was 49.6%.

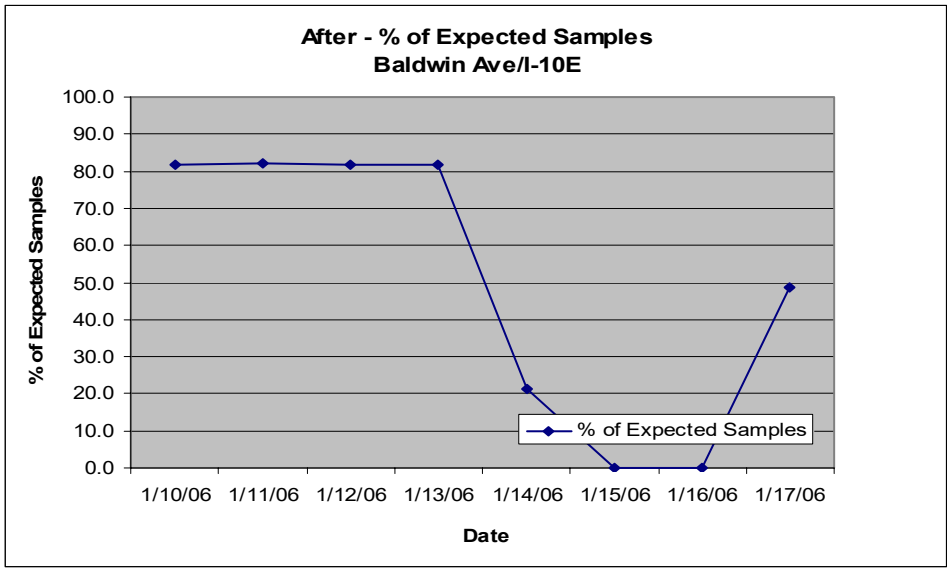

Figure 6: Baldwin Ave/I-10E – Before Scenario Results

Table 2: Baldwin Ave After Daily Communications Rate

Baldwin Ave After	
Date	**Communications Rate**
1/10/2006	81.6
1/11/2006	82.1
1/12/2006	81.6
1/13/2006	81.9
1/14/2006	21.2
1/15/2006	0.0
1/16/2006	0.0
1/17/2006	48.6
Average	**49.6**

Source: PeMS at http://pems.eecs.berkeley.edu/

Madre Street Location

As shown in Figure 7 and Figure 8, the communication rate (percentage of expected samples) in the "before" period (copper interconnect) ranged between 99.6% and 99.9% with an average of 99.8%. During the "after" period (with ENCOM wireless

communication in place), the communications rate ranged between 64.2 and 75.8% with an average of 72.9%.

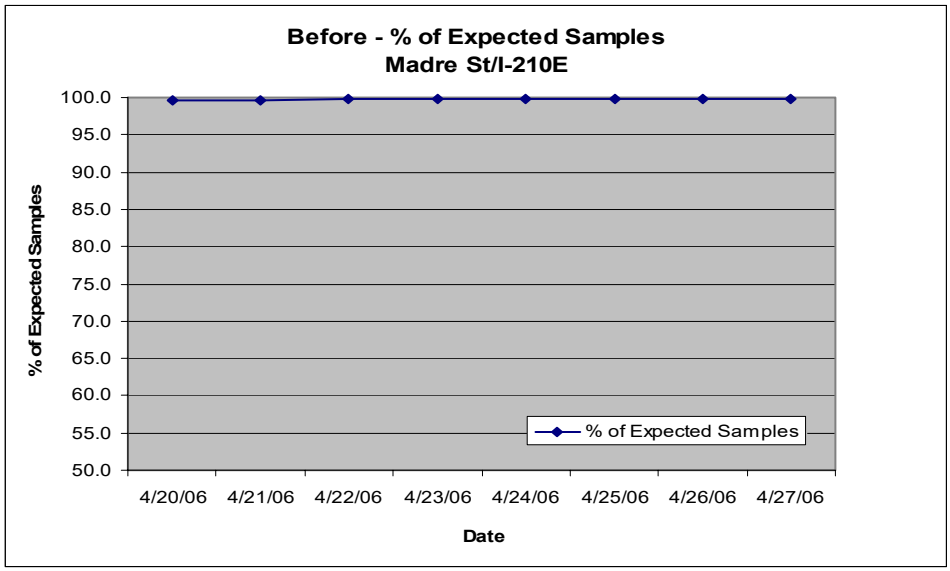

Figure 7: Madre St/I-210 E – Before Scenario Results

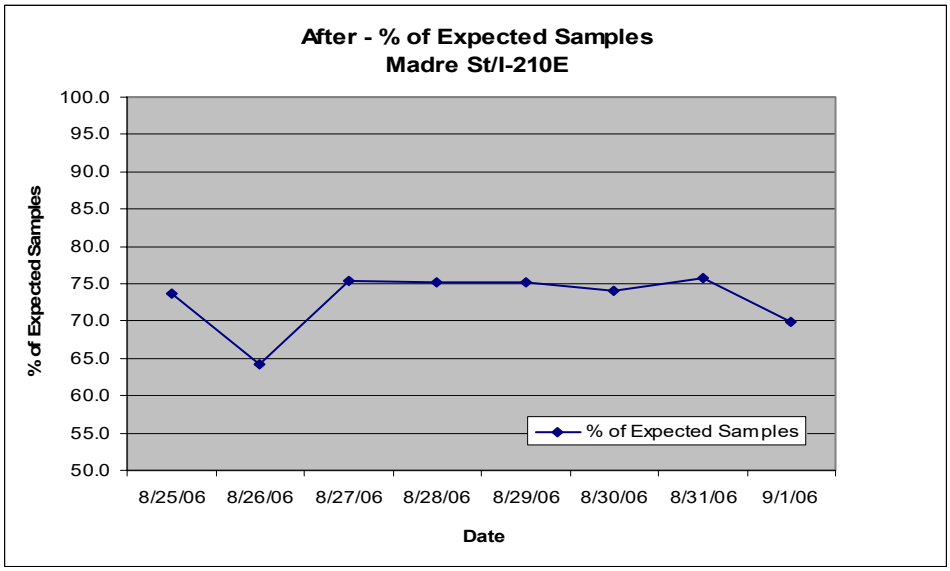

Figure 8: Madre St/I-210 E – After Scenario Results

Table 3: Madre St– Before and After Daily Communications Rate

Madre St Before		Madre St After	
Date	Communications Rate	Date	Communications Rate
4/20/2006	99.6	8/25/2006	73.8
4/21/2006	99.6	8/26/2006	64.2
4/22/2006	99.8	8/27/2006	75.3
4/23/2006	99.8	8/28/2006	75.2
4/24/2006	99.8	8/29/2006	75.1
4/25/2006	99.9	8/30/2006	74.1
4/26/2006	99.8	8/31/2006	75.8
4/27/2006	99.9	9/1/2006	69.8
Average	**99.8**		**72.9**

Source: PeMS at http://pems.eecs.berkeley.edu/

Transition Period Comparison

Additional analysis was completed to understand how the communication rate (% of expected samples) is affected during the transition to wireless communication. Figure 9 through Figure 11 and tables present these results.

Valley Boulevard Location

As shown in Figure 9, there was an interruption in communications at the Valley Boulevard location between 10/27/2005 and 10/31/2005 which coincides with the time that the ENCOM equipment was being installed. (The operational date for ENCOM is indicated in bold in the table).

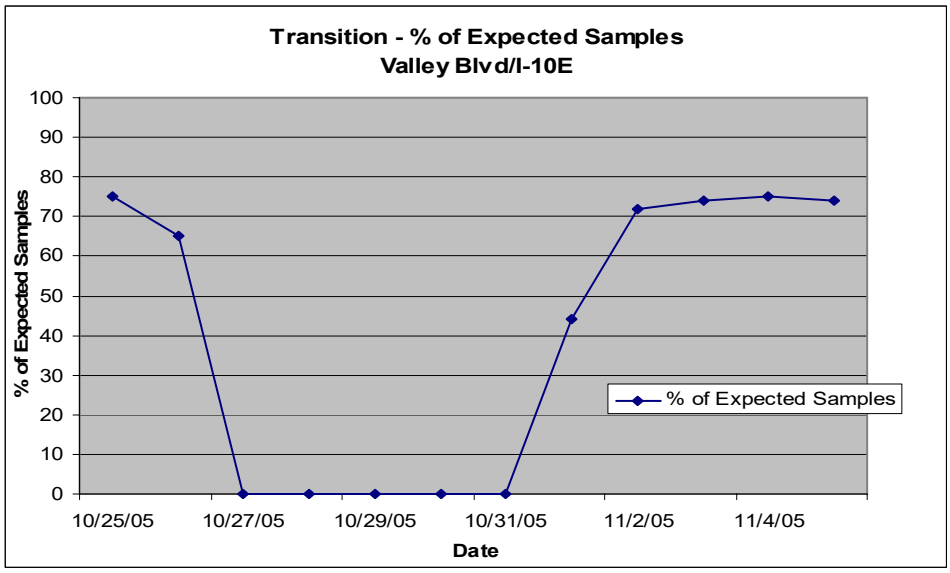

Figure 9: Valley Blvd/I-10 E – Transition Results

Table 4: Valley Blvd- Daily Communications Rate (Transition Period)

Valley Blvd	
Date	**Communications Rate**
10/25/05	75
10/26/05	65
10/27/05	0
10/28/05	0
10/29/05	0
10/30/05	0
10/31/05	0
11/1/05	**44**
11/2/05	72
11/3/05	74
11/4/05	75
11/5/05	74

Source: PeMS at http://pems.eecs.berkeley.edu/

Baldwin Avenue Location

As shown in Figure 10, there was no communication with the Baldwin Ave/I-10 E location until 10/31/2005 which coincides with the approximate operational date of ENCOM wireless at this location. (The operational date for ENCOM is indicated in bold in the table).

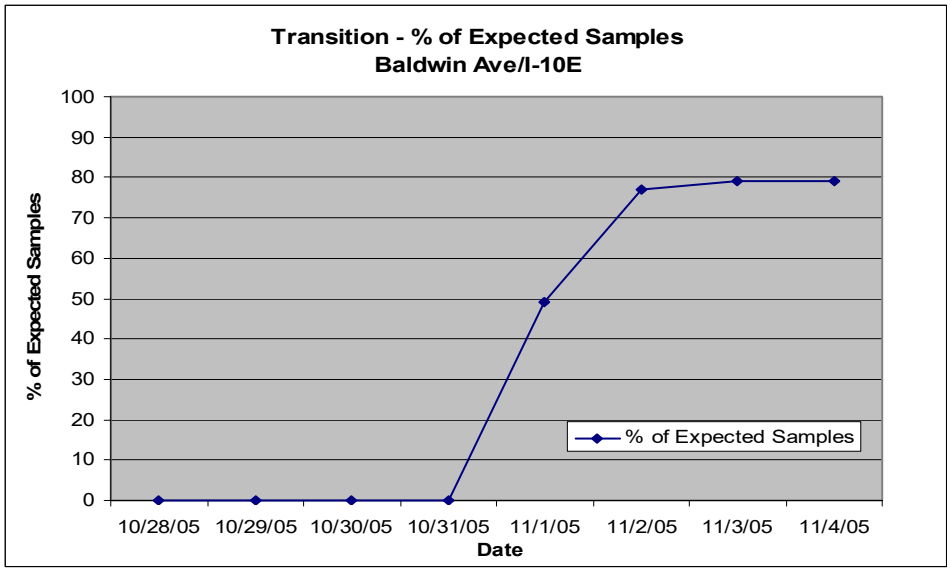

Figure 10: Baldwin Ave/I-10 E – Transition Results

Table 5: Baldwin Blvd- Daily Communications Rate (Transition Period)

Baldwin Ave	
Date	**Communications Rate**
10/28/05	0
10/29/05	0
10/30/05	0
10/31/05	0
11/1/05	**49**
11/2/05	77
11/3/05	79
11/4/05	79

Source: PeMS at http://pems.eecs.berkeley.edu/

Madre Street Location

Figure 11 indicates a drop in communication at Madre Street locations on 06/29/2006 wjocj coincides with the operational date of ENCOM wireless at this location ((The operational date for ENCOM is indicated in bold in the table).

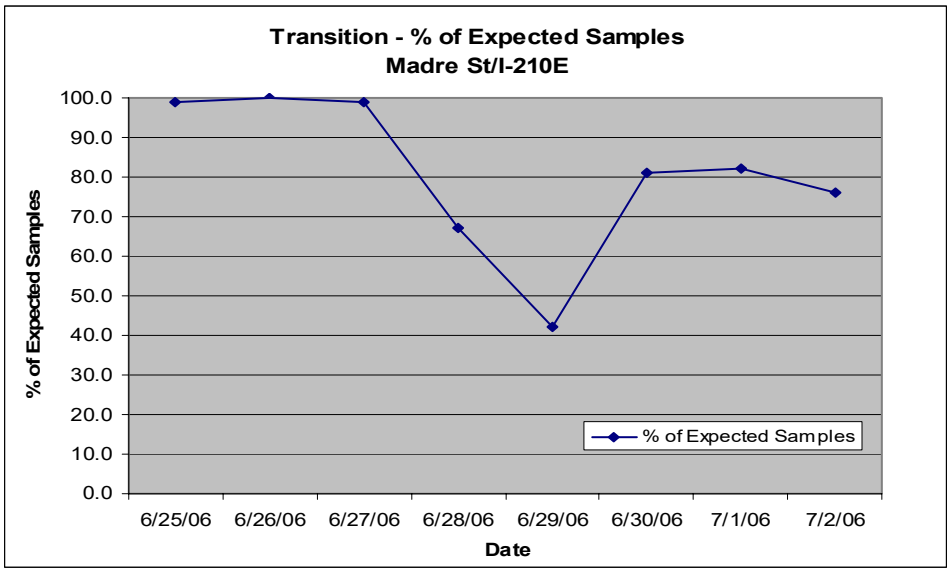

Figure 11: Madre St/I-210 E – Transition Results

Table 6: Madre St- Daily Communications Rate (Transition Period)

Madre St	
Date	**Communications Rate**
6/25/06	99.0
6/26/06	100.0
6/27/06	99.0
6/28/06	67.0
6/29/06	**42.0**
6/30/06	81.0
7/1/06	82.0
7/2/06	76.0

Source: PeMS at http://pems.eecs.berkeley.edu/

24-hour period analysis

Figure 12 below illustrates communication data (3-hour averages) for a 24-hour period within the below and after conditions at Madre St/I210E location. It does not appear that low light (during night time) conditions have an impact on the communications rate on either the hardwire connection or the ENCOM wireless application.

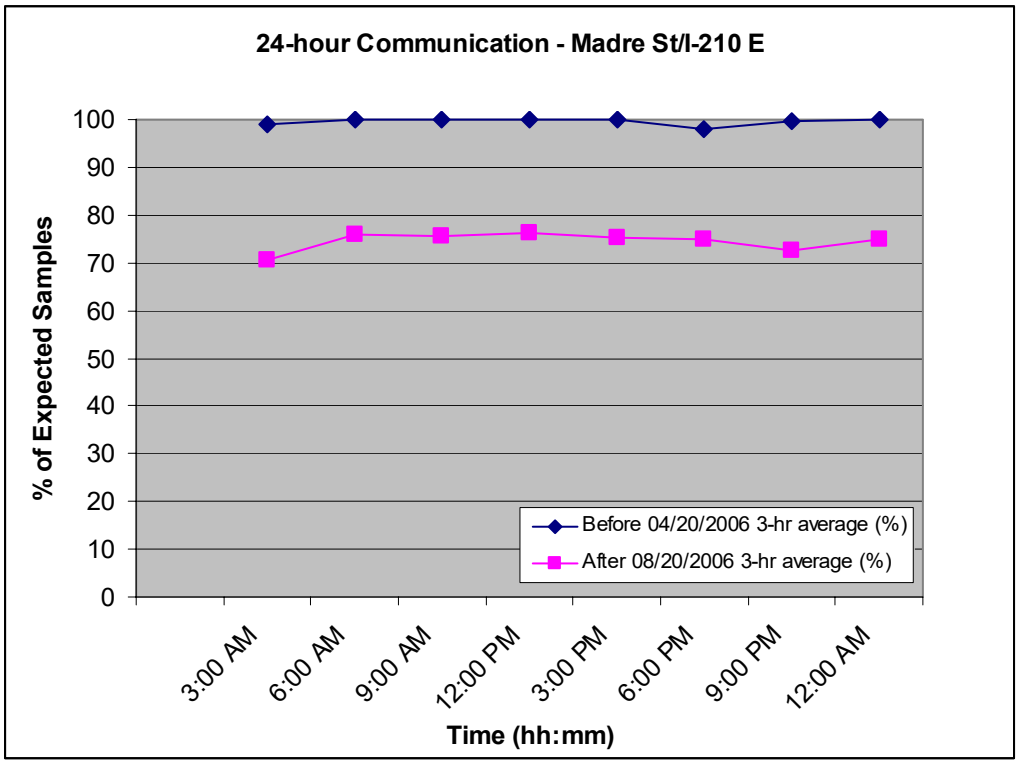

Figure 12: Madre Street/I-210E Hourly Communications Rate

Key Observations

Based on the above comparisons of the communications rate between the hardwire connection and the ENCOM wireless connection, it appears that the communications rate (percentage of expected samples) drops to the vicinity of 75% to 80% (compared to 99% with the hardwire connection). Lower communications rates could be attributed to various causes:

- Radio could be using an improper driver. The driver contains the instructions on how the radios should communicate with the device (handshaking, tx, rx, etc.) and the wrong driver could result in additional processing time. There are over 70 drivers available to allocate the needs of every traffic device (e.g. controllers, detectors, etc.) and ENCOM also creates custom ones as needed.
- There may be poor antenna alignment or a bad radio path. ENCOM radios come with a Spectrum analyzer that shows in real time possible sources of interference and the way to avoid them, they also have Remote Diagnostics tools that must be used during installation to ensure the best radio path has been selected.

The contractor for this installation is typically informed about the correct driver to use and has experience with wireless installation. They did not request ENCOM help in trouble-shooting the installations.

In general, an ENCOM wireless connection can be installed more quickly than a traditional hardwire connection and with less disruption to traffic. While the radio may be more expensive that a traditional copper FSK modem, utilizing an ENCOM wireless radio may be more cost effective depending on the length of conduit and cable that is being replaced. Assuming an installation cost of $50 per foot for conduit, the ENCOM wireless solution could be cost effective at 130 feet, and perhaps even shorter if one considered a reduced traffic control cost.

7. Recommendation to Caltrans

PROS	CONS
Does not require trenching or directional drilling for installation of conduit; avoids traffic disruption due to conduit installation	Requires near line of sight between antennas free of obstructions due to buildings and vegetation.
May be less expensive in situations where conduit installation is expensive or difficult to install.	Additional ongoing troubleshooting/ equipment configuration may be required over hardwire connections.
Can be installed more quickly than when conduit installation is required; useful as a temporary solution when hardwire communication cables are broken or are removed during construction.	Increased maintenance to trim vegetation could be needed to maintain line of sight.
Uses RS232 and FSK protocols commonly used by traffic controllers.	Line of sight could be blocked by future buildings.
Utilizes license-free, low-power frequencies for communications.	Antennas might attract unwanted attention to cabinets; issues related to damage and theft of equipment might arise.
Can handle point-to-point and point-to-multipoint configurations.	Drilling holes in the cabinet walls could be required for antenna cables; these holes are additional location for dirt, dust and moisture to enter cabinet. If ENCOM equipment is relocated to another location, these holes would need to be sealed.

Appendix A
Vendor Specification Sheet

5100 S/R

COMMPAK™ Model 5100 S/R Wireless Interconnect Unit

Features

- License-Free, Frequency-Hopping Spread Spectrum Technology
- Up to 115kbps Sustained Data Throughput
- End-to-end Delays of less than 8 milliseconds
- 2 and 4 wire FSK interface (Bell 202 / 1200 baud only)
- Available as a Standalone Shelf Unit, Weatherproof Pole Mount or 170/TS1/TS2 Detector Rack Card
- Up to 20 Mile Range (with L.O.S.)
- Store and Forward Repeater Standard
- Full Duplex Capability
- Transparent Operation with Asynchronous Traffic Applications
- High Performance Receiver
- Built-in Setup and Diagnostics Capabilities
- Variable Output Power Capability – Maximum 1 Watt
- Completely Configurable with Windows™ Based **ControlPAK™** Software (included)
- Compatible with the **COMMPAK™** Model 5200 Radiomodem products

Description

The **COMMPAK™** 5100 has been specifically designed to provide robust, reliable performance in Traffic Interconnect Applications. Blazing throughput, extended range and enhanced interference avoidance methods, coupled with ease of setup and installation provide unequalled performance in Point-to-Point or Point-to Multipoint networks.

The Model 5100 may be operated as a Master, Remote or Repeater. Configuration of the Model 5100 is simple and straightforward, using the provided Windows™ based **ControlPAK™** software. For standard traffic interconnect applications, a wide range of prebuilt and pretested application files are included, allowing "plug-and-play" setup for your specific controllers. Most major controller manufacturer's products and third party applications are represented.

The Model 5100 provides a standard RS232 serial port, as well as a 2 or 4 wire FSK interface. Store and Forward Repeater capabilities for extending range beyond Line-of-Sight are standard in the Model 5100.

The Model 5100 is available as a standalone shelf mount unit, or as a card designed to plug into, and draw power from a 170/TS1/TS2 detector rack. Field installation could not be simpler!

With **COMMPAK™**, Wireless is Simple!

ENCOM™

Wireless Data Solutions

www.encomwireless.com

Wireless Solutions for Traffic Monitoring and Control

COMMPAK™ Model 5100 S/R Specifications

Radio Specifications		900MHz	2.4GHz
Technology:		FHSS[1]	FHSS[1]
Frequency Range:		902-928 MHz	2.400-2.4835 GHz
Output Power:		1mW, 10mW, 100mW, 1000mW	10, 50, 100, 250, 500, 750, 1000mW
Software Programmable:		Yes	Yes
Available Hop Patterns:		62	44
Number of RF Channels:		139	202
RF Channel Spacing:		200KHz	400KHz
Error Checking:		16 Bit-CRC	16 Bit-CRC
Error Correction:		Forward Error Correction	Forward Error Correction
Encryption:		32 Bit	32 Bit
Receiver Sensitivity / BER:		-110 dBm @10^{-6} BER	-110 dBm @10^{-6} BER
System Gain:		152 dBm	152 dBm
Antenna Port:	5100S	RP TNC-F	RP TNC-F
	5100R	RP SMA-F	RP SMA-F
Certification:		FCC, Industry Canada	FCC, Industry Canada
Operating Modes:		Transceiver	Transceiver
System Configurations:		Point to Point, Point to Multipoint, Multipoint to Point, Multipoint to Multipoint.	

[1]Frequency Hopping Spread Spectrum Technology

General Specifications		900MHz	2.4GHz
Input Power:	5100S	6-30 VDC	6-30 VDC
	5100R	Powered by the Detector Rack via the edge connector	Powered by the Detector Rack via the edge connector
Power Consumption:		Typical <100mA (standby), <125mA (100mW TX)	
Operating Environment:		-40˚C to +80˚C (-40˚F to 176˚F)	-40˚C to +80˚C (-40˚F to 176˚F)
Humidity:		95% Non-condensing	95% Non-condensing
Physical Dimensions:	Shelf Mount (5100S)	2.00”W x 5.00”H x 9.00”D	2.00”W x 5.00”H x 9.00”D
	Enclosure Type (Shelf)	Milled Aluminum Black Powder Coat	Milled Aluminum Black Powder Coat
	Rack Mount (5100R)	1.125”W x 4.50”H x 7.0”D	1.125”W x 4.50”H x 7.0”D
	Detector Connector (Rack)	2x22 pin edge card with 0.156” ctr.	2x22 pin edge card with 0.156” ctr.

Software Specifications	900MHz	2.4GHz
Radio Configuration:	Yes	Yes
Spectrum Analyzer:	Yes	Yes
Remote Diagnostics & Configuration	Yes	Yes:

Interface Specifications		900MHz	2.4GHz
Programming:		DB9-F	DB9-F
Data Interface:	Standard	RS232 Asynchronous	RS232 Asynchronous
	Optional	2 or 4 Wire FSK, Bell 202	2 or 4 Wire FSK, Bell 202
Data Format:	Parity	None, Odd or Even	None, Odd or Even
	Data Bits	7 or 8	7 or 8
Data Rate:	RS232	1200 bps - 115.2 kbps	1200 bps - 115.2 kbps
	FSK	1200 bps	1200 bps
Data Transmission:		Key-by-data or RTS data input framing with programmable RTS/CTS time delay	Key-by-data or RTS data input framing with programmable RTS/CTS time delay

Indicators 900MHz	2.4GHz	
TX Data, RX Data, PWR:	Yes	Yes
Data Port Indicator:	Yes	Yes
RSSI:	Yes	Yes

****ENCOM reserves the right to make changes to specifications of products described in this data sheet at any time without notice.** **Rev #02-0203**

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Calgary, Alberta, Canada T2E 7J9
Phone (403) 230-1122
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www.encomwireless.com

ENCOM™
Wireless Data Solutions

SERIAL RADIO 5200

Wireless Interconnect

The Model 5200 has been specifically designed to provide robust, reliable performance for the transfer of serial data. Blazing throughput, extended range and enhanced interference avoidance methods, coupled with ease of setup and installation provide unequalled performance in Point-to-Point or Point-to Multipoint networks.

Configuration of the Model 5200 is simple and straight forward, using the provided ControlPAK™ software. For standard traffic interconnect applications, a wide range of prebuilt and pretested application files are included, allowing plug-and-play setup for your specific controllers. Most major controller manufacturer's products and third party applications are represented.

The Model 5200 is fully compatible with the 5100 Series of Wireless Interconnect products, allowing wireless network configurations that may include a mix of RS232, RS485 and 2 or 4 wire FSK.

Store and Forward repeater capabilities for extending range beyond Line-of-Sight are standard.

Features

- License-Free, Frequency-Hopping Spread Spectrum Technology
- Up to 20 Mile Range (with L.O.S.)
- Transparent Operation with most Traffic Applications
- High Performance Receiver
- Built-in Setup and Diagnostics Capabilities
- Built-in Store & Forward Repeater Capability
- Completely Configurable with Windows Based ControlPAK™ Software (included)

SHELF MOUNT	RACK MOUNT
5200 S	5200 R
	

Three great reasons to choose products from ENCOM Wireless Data Solutions Inc:

1

Cut costs by cutting out the wires.

2

Save time with simple set-up and installation.

3

Enjoy **secure** and reliable communication.

ENCOM™

Wireless Data Solutions

Model 5200 Specifications

Radio Specifications		900MHz 2.4GHz	
Technology:		FHSS1	FHSS1
Frequency Range:		902-928 MHz	2.400-2.4835 GHz
Output Power:		1mW, 10mW, 100mW, 1000mW	10, 50, 100, 250, 500, 750, 1000mW
Software Programmable:		Yes	Yes
Available Hop Patterns:		62	44
Number of RF Channels:		139	202
RF Channel Spacing:		200KHz	400KHz
Error Checking:		16 Bit-CRC	16 Bit-CRC
Error Correction:		Forward Error Correction	Forward Error Correction
Encryption:		32 Bit	32 Bit
Receiver Sensitivity / BER:		-110 dBm @10-6 BER	-110 dBm @10-6 BER
System Gain:		152 dBm	152 dBm
Antenna Port:		RP TNC-F	RP TNC-F
Certification:		FCC, Industry Canada	FCC, Industry Canada
Operating Modes:		Transceiver	Transceiver
System Configurations:		Point to Point, Point to Multipoint, Multipoint to Point, Multipoint to Multipoint.	
1Frequency Hopping Spread Spectrum Technology			
General Specifications		**900MHz**	**2.4GHz**
Input Power:		6-30 VDC	6-30 VDC
Power Consumption:		Typical <100mA (standby)	<125mA (100mW TX)
Operating Environment:		-40ºC to +80ºC (-40ºF to 176ºF)	-40ºC to +80ºC (-40vF to 176ºF)
Humidity:		95% Non-condensing	95% Non-condensing
Physical Dimensions:		3.65"W x 1.69"H x 4.38"D	3.65"W x 1.69"H x 4.38"D
Weight:		12 oz	12 oz
Enclosure Type:		Milled Aluminum Black Powder Coat	Milled Aluminum Black Powder Coat
Software Specifications		**900MHz**	**2.4GHz**
Radio Configuration:		Yes	Yes
Spectrum Analyzer:		Yes	Yes
Remote Diagnostics & Configuration:		Yes	Yes
Interface Specifications		**900MHz**	**2.4GHz**
Programming Port:		DB9-F	DB9-F
Data Interface:	Standard	RS232 Asynchronous	RS232 Asynchronous
	Optional	RS485 (2 or 4 wire)	RS485 (2 or 4 wire)
Data Rate:		1200 bps - 115.2 kbps	1200 bps - 115.2 kbps
Data Format:	Parity	None, Odd or Even	None, Odd or Even
Data Bits		7 or 8	7 or 8
Data Transmission:		Key-by-data or RTS data input framing with with programmable RTS/CTS time delay	Key-by-data or RTS data input framing with programmable RTS/CTS time delay
Data rate in RF Channel:		172.8 kbps	172.8 kbps
Indicators		**900MHz**	**2.4GHz**
TX Data, RX Data, PWR:		Yes	Yes
RSSI:		Yes	Yes

**ENCOM reserves the right to make changes to specifications of products described in this data sheet at any time without notice.

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ENCOM™
Wireless Data Solutions

Appendix B
Equipment Installation Photos

Valley Blvd Demarcation Box and Antenna

Baldwin Ave Demarcation Box and Antenna

Madre St On-ramp Cabinet and Antenna

Madre St On-ramp – Looking West

ITS Pilot Project Demonstration

Circumnav (Dash Navigation) Evaluation

Prepared for Caltrans

September 2006 FINAL

Prepared By Kimley-Horn and Associates

ITS Pilot Project Evaluation

Circumnav (Dash Navigation)

Vendor Contact Information:

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http://www.dash.net

Evaluation Summary

Vendor/Project – Circumnav Networks/Dynamic Route Advisory System

Circumnav Networks is deploying a dynamic route advisory system. The system requires users to purchase an in-vehicle device (OBU, On-Board Unit). Using fixed roadside access points (RSU, Road Side Unit) deployed by Circumnav Networks and Wi-Fi and cellular communications, the vehicles provide real-time probe vehicle data (speed, location, and direction) to Circumnav system. The vehicles, in turn, receive optimal routes and up-to-the-minute estimated travel time data from the Circumnav system. "Circumnav Networks" changed their name to "Dash Navigation" in August 2006.

Circumnav's plans changed during the course of this evaluation, and the deployment of RSUs is not a current focus in their business plan. As a result, the full extent of the originally planned RSU system was not tested, and the evaluation plan was adjusted to match available information. This evaluation focuses on vehicle-to-vehicle and vehicle-to-roadside communication aspects of Circumnav's original RSU plan. Based on the trial data provided by Circumnav, there appears to be sufficient communications capabilities to support the originally planned RSU system.

Delivery: Does demonstration satisfy Vendor's stated objectives for Caltrans as below?

Provide optimal travel routes for users based on real-time traffic conditions	☐ YES ☐ NO ☒ NOT VERIFIED
Receive speed, location, and directional data from probe vehicles	☐ YES ☐ NO ☒ NOT VERIFIED
Provide sufficient communication capabilities to provide optimal travel routes and estimated travel times to in-vehicle users based on real-time traffic conditions	☒ YES ☐ NO
Provide sufficient communication capabilities to receive speed, location, and directional data from probe vehicles	☒ YES ☐ NO

Key Observations

According to the data provided by Circumnav, the technology is capable of transmitting enough data between vehicle and roadside units to obtain probe data from the vehicle and send regional travel information to the vehicle. The average test data size is over 2 MB and average transfer lasted 20 seconds. According to Circumnav, each Bay Area real-time traffic update file's size would only be 10-50 kb. Therefore, it appears that the transfer rate, an average of approximately 100 kbps, and duration of transmission, an average of approximately 20 seconds, would allow for successful operation of the system. The failure rate of transmissions could not be determined with the data provided. In addition, factors such as weather and topography that could affect the communications capabilities did not appear to be tested. According to the data provided, it appears there is a significant amount of excess capability to handle some or all of these factors.

More detailed and plentiful data was provided for vehicle-to-vehicle communications, allowing for a more in-depth evaluation. All runs achieved a connection of at least 7 seconds that was classified as "good" (connection quality above 50). The average time with a continuous "good" connection was 20 seconds. The average separating distance at which a "good" connection was reached was 526 meters. As noted by Circumnav and design, communications were significantly stronger when the vehicles were approaching each other than when they were increasing their separating distance. The speed differential for communicating vehicles ranged from 14 to 133 mph does not bring significant variation to connection quality. Assuming the file transfer rate, duration, and quality for vehicle-to-vehicle connections can be achieved for vehicle-to-roadside connections, and that only 10-50 kb of data would need to be transferred with each transmission, even the shortest "good" connection time experienced in the trials provided would have been able to transfer all required data. The test runs were conducted on flat terrain, so the affects of topography did not appear to be tested.

Recommendation to Caltrans

PROS	CONS
Allows in-vehicle visual access to real-time traffic data	It requires a large number of probe vehicles and roadside devices to obtain valid data
Collects traffic data from probe vehicles, including information on major arterials	Recurring cellular connection costs to roadside units
Allows for map and yellow pages updates without user involvement	There may be a capacity limit of how many vehicles can communicate with each other and a single roadside device .
Allows data to be transmitted between passing cars and between vehicles and roadside devices	Topography, roadway curvature and speed differential may impact the communications performance shown in the trial data.
Can determine and distribute arterial roadway traffic conditions	Limited data available for vehicle-to-roadside communications.
Wi-Fi connections allow vehicle-to-roadside and vehicle-to-vehicle communication allows sharing of traffic information without incurring cellular data costs.	Currently the road side units are installed with call boxes. While call boxes are phasing out, feasible location for road side units may be difficult to determine.
New road construction and improvements information can be automatically determined and distributed by system	
Minimal installation cost and impact to existing roadway equipment.	

Evaluation Details

1. Delivery

Vendor's Stated Objective

In Caltrans contract:

- ❒ *Provide in-vehicle real-time personalized roadway traffic information*
- ❒ *Provide cost-effective navigation solution*
- ❒ *Notify drivers of quickest route and estimate time of arrival*
- ❒ *Obtain speed, location, and direction information from user vehicles*
- ❒ *Exchange information with vehicles via roadside Wi-Fi access points*

Additional Assertions:

- ❒ *1 hour installation*
- ❒ *24 hour coverage via solar panel at roadside access points*
- ❒ *Connectivity between access point and vehicle via Wi-Fi for 1-2 km*

2. Project Specifics

Deployment Date(s) and Time(s)	Evaluation Date(s) and Time(s) *Include weather conditions*
Deployed September, 2005 Communications with roadside devices have since been terminated.	**Beta 1 testing was completed by December 2005 (**Date of testing was not provided by Circumnav.)
Deployment Location(s) *Include diagram or map if applicable*	**Evaluation Location(s)** *Include diagram or map if applicable*
8 sites in Bay Area as part of Beta test: • **2 on I-280** • **6 on SR-101**	**Evaluated only at SR-101 locations**

Circumnav's plans changed during the course of this evaluation, and the deployment of roadside units (RSUs) is not a current focus in their business plan. As a result, the full extent of the originally planned RSU system was not tested, and the evaluation plan was adjusted to match available information provided by Circumnav. This evaluation focuses on vehicle-to-vehicle and vehicle-to-roadside communications of Circumnav's original RSU plan.

3. Technology

3.1 Technology or System Description

Circumnav Networks (renamed Dash Navigation in August 2006) installed RSUs at existing call box locations along two major freeways, I-280 and SR-101, in the Bay Area. Each RSU is self-enclosed unit that contains a Central Processing Unit (CPU),Wi-Fi antennas, and a GPRS modem. Power for the unit is provided by a solar panel that is larger than is currently used for call boxes. The existing call box poles were chosen for their availability for this demonstration. A full-scale deployment of the RSUs would likely require the installation of new support infrastructure, such as poles or cabinets, to hold the RSUs.

Circumnav plans to offer on-board units (OBUs) that could be installed on vehicles. Each OBU includes a driver-interface navigation device, a GPS unit and a Wi-Fi antenna. The OBU carries an initial purchase cost, with an additional annual subscription fee to the Circumnav service. It requires 12 V of accessory power or professional installation to integrate it to the vehicle's electrical system.

As originally envisioned by Circumnav, the RSUs were to be used as Wi-Fi wireless connection points for collecting and transmitting data between the Circumnav system and each OBU. As vehicles pass by the RSU, data would be exchanged between the RSU and OBU using the wireless antennas (through the rear of the vehicle). Vehicles would provide real-time probe vehicle data (speed, location, and direction) to Circumnav system, and, in turn, receive optimal routes and up-to-the-minute estimated travel time data from the Circumnav system. The RSU computer processes all data it receives from the OBU, but does not send redundant data over the GPRS link.

3.2 Previous Evaluations (including vendor's own) and/or Similar Technology Deployments

Alpha testing has been completed by Circumnav. These evaluations included testing of vehicle-to-vehicle communications and vehicle-to-roadside communications. Evaluation results from this previous test was not available, but was reported to be successful by the Vendor.

4. Performance Measurement

Performance measures are defined here for this project and are divided into different categories for evaluation and discussion: Quantitative, Qualitative, and Other Performance Factors. The performance measurement results are presented with the measures.

Definition of Performance Measures

What does the technology or system measure?
Circumnav's system was designed to obtain speed, location, and direction from its vehicles OBUs and send travel information to vehicles through the RSUs. The probe traffic data could be combined with other data sources for the Bay Area 511 system to provide real-time link travel time information and optimal route-selection. Actual testing only examined the capabilities of vehicle-to-vehicle and vehicle-to-roadside communications, and actual probe, traffic data and route data were not exchanged between the vehicle and road side units or between vehicles in the evaluation.

Table 1 describes the connection quality classification for each of the trial runs analyzed. This connection strength, a standard Wi-Fi parameter, is calculated by Circumnav to indicate the relative quality of a wireless signal. The maximum quality on this scale is 92.

Table 1: Connection Quality Description

Connection Strength	Connection Quality
80-92	Excellent
70-80	Very Good
50-70	Good
30-50	Fair

4.1 Quantitative Outputs

Accuracy

Since actual probe, traffic data and route data were not used in the evaluation, the accuracy of such information cannot be evaluated.

Cost

1. *What is the cost of an individual road side unit, including installation?*

   Each road side unit costs approximately $3,000 to manufacture. Circumnav pays their installer, Comarco, less than $500 per site for installation.

2. *What are the user costs of an individual vehicle on-board unit?*

   Circumnav estimated the vehicle on-board unit to cost under $1,000 with an all-inclusive subscription fee of $10-$15 per month that will provide access to real time traffic information, map updates, yellow pages updates. On September 26, 2006, Circumnav publicly unveiled their device. The device is planned to be available to the general public in early 2007. Exact pricing of the

unit or the subscription service was not announced, and it was indicated that this would be available at a later date.

3. *What is the frequency and cost of maintenance to the road side units?*

   No maintenance was required during the test deployment of the road side units. Each RSU is anticipated to last approximately 3 years, depending on battery life.

4. *What is the cost of backhaul communication bandwidth per road side unit?*

   According to the vendor, this cost is $45 per month per site using T-Mobile's GPRS network.

Reliability

Communications

1. *What is the failure rate for data transfers between the road side unit and the vehicle?*

   This could not be determined from the data provided by Circumnav.

2. *Does the failure rate depend on the average speed of the vehicle?*

   No data correlating the time of connection to vehicle speed was provided.

3. *Does the failure rate depend on the type of vehicle?*

   Circumnav noted that in general, the higher up on the vehicle that the onboard unit is mounted, the better communications will be. In addition, communications quality is also dependent on the type of glass in the vehicle.

4. *Does the failure rate depend on the type of vehicle windshield glass?*

   According to the vendor, approximately 10-12 different model vehicles of different windshield glass type were tried in the test, and no issues have been found to do with signal attenuation due to windshield metallization issues.

5. *Does the failure rate depend on topography?*

   The trial locations were selected in part due to their flat topography. Circumnav estimates that there would be some reduction in transmission quality and duration with varying topography, but the extent of this reduction is unclear.

6. *What is the failure rate for data transfers between vehicles?*

   Of the 84 vehicle-to-vehicle runs provided by Circumnav, every run consisted of a good quality connection that lasted at least 7 seconds.

7. *Does the failure rate depend on the average speed differentials of the vehicles?*

   Figure 1 summarizes the relationship between the transmission quality and vehicle speed differentials. There is no significant correlation between the transmission quality and the vehicle speed differentials.

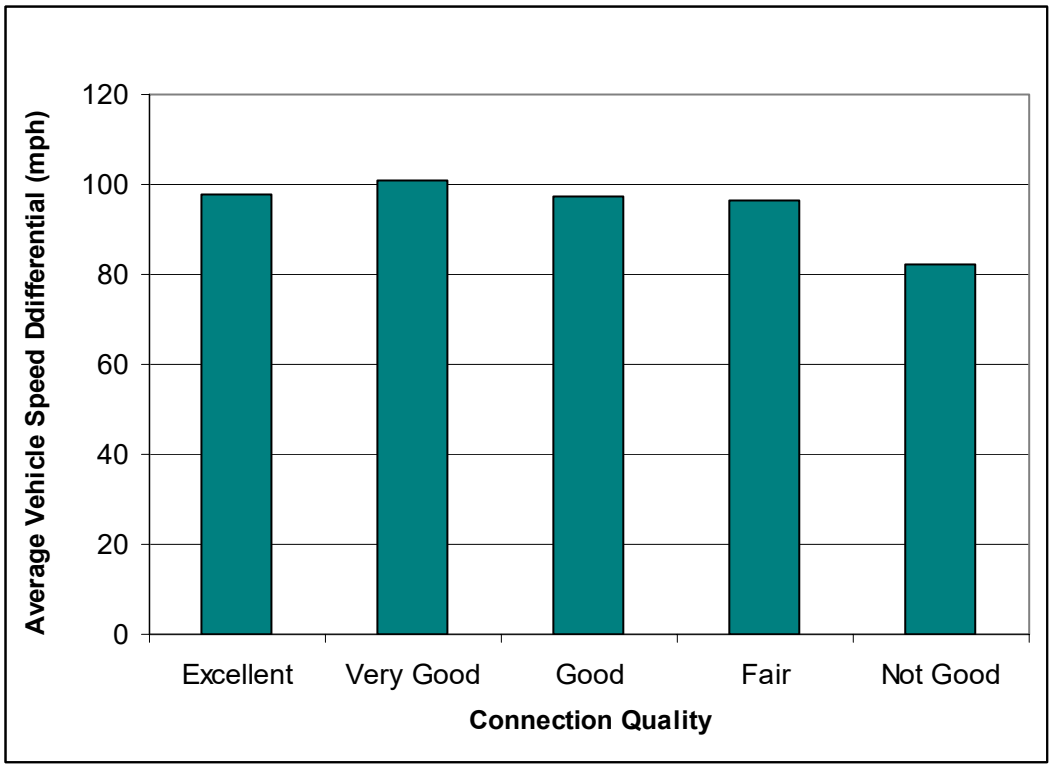

Figure 1: Average Vehicle Speed Differential versus Connection Quality

8. *Does the failure rate depend on the type of vehicles?*

   The data provided by Circumnav did not include vehicle type information. The vendor claims that there will be some variability depending on the mounting location of the onboard unit, but that this variability is not significant enough to affect the use of the onboard unit.

9. *Does the failure rate depend on topography?*

   This information is not available since all testing was conducted on relatively flat terrain.

10. *Does the failure rate depend on time of day?*

    The data provided by Circumnav did not include time of day information. .

Devices

11. *Was there a failure of a roadside unit during the evaluation? If yes, what was the length of time of the failure?*

    ☐ **YES** ☒ **NO**

12. *Did the solar panel provide 24-hour power support on all units?*

    ☐ **YES** ☒ **NO**

    By design, Circumnav limited RSU operation to approximately 18 hours per day to ensure reliability with respect to the solar panel size and battery capacity.

13. *Did any devices need to be replaced or repaired during the evaluation? If so, how many and what was the amount of time before the replacement or repair and the cost of the replacement/repair?*

    ☐ **YES** ☒ **NO**

Productivity

1. *How often is data exchanged between the vehicle and roadside unit?*

   It is estimated that under Circumnav's original deployment plan, data would be exchanged between vehicles and roadside units every 5-10 minutes. The original deployment plan included roadside units placed 5-10 miles apart along major metropolitan freeways. Assuming an average vehicle freeway speed of 60 mph, a vehicle would encounter a roadside unit every 5-10 minutes. (No information is available regarding how often data would be exchanged between vehicles and the Circumnav system in their new business plan.

2. *What is the average length of time of road side to vehicle transmission?*

   20 runs of data road side to vehicle, at 5 road side unit locations, were provided by Circumnav. Of these 20 runs, the average transmission lasted 20 seconds. Circumnav indicated that the transmission duration depends on the size of file to be transmitted.

3. *What is the average file size of each road side to vehicle transmission?*

   Of the 20 runs of data provided by Circumnav, the average transmission consisted of 2.16 MB of data. No distinction was made between vehicle-to-roadside and roadside-to-vehicle transmission file sizes.

4. *What is the anticipated size of a 511 traffic data packet that would be sent by the road side unit to vehicle onboard unit?*

   Circumnav estimated the 511 traffic data packet size to be 10-50 kb.

5. *What is the anticipated size of a probe data packet that would be sent from the vehicle onboard unit to the road side unit?*

   Circumnav estimated the probe data packet size to be 10-50 kb.

6. *What is the anticipated size of non-time-critical data updates, such as map and yellow pages that would be sent from the road side unit to the vehicle onboard unit?*

   Circumnav estimated the non-time-critical data updates size to be 10-50 kb. These updates would be incremental, not major upgrades.

7. *What is the average duration of a vehicle-to-vehicle transmission?*

   The average duration of vehicle-to-vehicle transmission was 41 seconds. The average duration vehicle-to-vehicle transmission during which there was a continuous good (or better) connection was 20 seconds. Figure 2 shows that transmissions with higher connection quality contain shorter continuous connection duration.

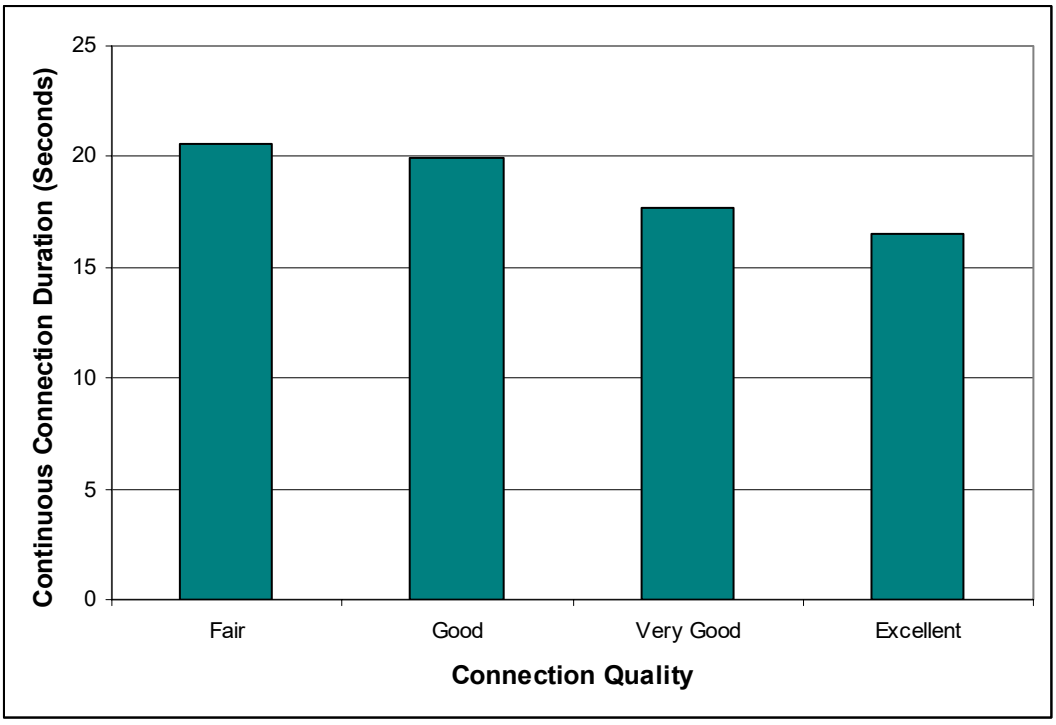

Figure 2: Continuous Connection Duration versus Connection Quality

8. *What is the average file size of each vehicle-to-vehicle transmission?*

   The file size of each transmission was not provided by Circumnav.

9. *What is the anticipated size of a probe data packet that would be sent between vehicles?*

   Circumnav estimated the vehicle-to-vehicle data packet size to be10-50 kb.

4.2 Qualitative Outputs

Accuracy

The accuracy of traffic information transmission cannot be determined since actual probe, traffic data and route data were exchanged in the evaluation. (Only test data packets were used.)

Reliability

1. *How would the vehicle onboard unit respond if communication with road side unit is not successful?*

   This information was not provided by Circumnav.

2. *Can Caltrans maintain and/or install the device (roadside units)?*

   The road side units were manufactured by Circumnav and installed by Comarco. Caltrans is notified of the location and time of installation. No additional maintenance or installation support by Caltrans is required. The system and equipment would be maintained and supported by Circumnav.

Cost

1. *How many road side units will be needed to provide sufficient regional coverage?*

   According to Circumnav, less than 100 road side units would be required to provide regional coverage. The road side units would be spaced every 5-10 miles on the Bay Area's 400 miles of freeway network.

2. *How would deployment costs road side unit costs be impacted if highway call box locations are not available?*

   Highway call boxes are gradually being phased out and a full-scale deployment of a network of road side units would require the installation costs of roadside cabinets or poles. While the cost of the individual RSUs would remain the same, the overall installation costs would increase. It is estimated that furnishing and installing a 1-B pole would be approximately $2,500 and

furnishing and installing a cabinet would be $9,000. Since Circumnav's current business plan does not include deployment of RSUs, the availability of highway call boxes would not impact the deployment cost.

Productivity

1. *Are privacy concerns addressed?*

   ☐ YES ☐ NO ☒ NOT VERIFIED

   According to Circumnav, privacy concerns are addressed in their system development. The system was not available for evaluation, so this information could not be verified.

2. *Does the inability to distinguish between HOV and SOV lanes greatly diminish the benefit provided by the system?*

   While the system's inability to differentiate speeds in HOV and SOV lanes could mislead the user, the route guidance should still be relatively accurate through the use of historical data,

3. *While integration with 511 is not planned, is the data generated by vehicle probes in a format capable of providing information to 511?* .

   ☒ YES ☐ NO ☒ NOT VERIFIED

   According to Circumnav, their data format is the same as that used by the 511 system. The system was not available for evaluation, so this information could not be verified.

4. *How do these performance measures relate to Caltrans' 9 Performance Measures?*

   Caltrans' performance measures are used to assess the operations of multi-modal transportation systems in order to create a more accountable framework for decision making. The following table relates the project performance measures against the Caltrans performance measures.

	Caltrans' 9 Performance Measures								
	Mobility/Accessibility/ Reliability	Productivity	System Preservation	Safety	Environmental Quality	Coordinated Transportation and Land Use	Economic Development	Return on Investment	Equity
Outputs Measured									
Accuracy (N/A)									
Cost	X		X					X	X
Reliability	X								
Productivity	X	X					X	X	

4.3 Performance Factors

Interoperability and compatibility

The Circumnav system has the potential to add numerous real-time and historical traffic speed data points to the 511 system. In particular, 511's travel time feature would be enhanced through additional data from the Circumnav system. The Circumnav system also has the potential to provide arterial speed information if RSUs were installed along the arterial network.

The system has been observed to easily integrate with existing call box equipment. It requires modification of standard call box equipment and installation only takes 45 minutes. All of the required technology can be placed on the modified call box unit. According to Circumnav, the OBU is compatible with all types of vehicles.

Scalability and Sensitivity

The benefit of the system is highly dependent on both the number of roadside units and the number of users. Accurate roadway speed information can not be provided without a large number of data points. The more users that have the OBU, the more frequently those users will pass and share data that can eventually be passed on to other vehicles and road side units. Circumnav estimated the critical number of users to be 1,000 to 5,000.

No testing was performed to estimate the number of vehicles that can communicate successfully with one road side unit. The number of road side units is not likely restricted by communications limitations, but no testing in this area has been performed.

The market for these Circumnav's device and services is still developing, and information was not provided regarding the relationship between user costs and market penetration. Prohibitively high user costs would reduce market penetration and diminish the number of users as sources of real-time data; this could limit the effectiveness of the system. On September 26, 2006, Circumnav publicly unveiled their device, but pricing of the unit or the subscription service was not announced (would be available at a later date.) The list price for other in-vehicle stand-alone navigation devices range from $499.99 to $899.99.

Safety

The use of probe vehicles should allow for a more accurate representation of average freeway speeds. Therefore, it should be easier to detect incidents on freeways. While the cause of a slowdown cannot be determined merely from vehicle speeds, the potential locations of incidents can be more easily identified.

Staffing and Training

The limited testing performed on the system did not allow determination of maintenance requirements for both road side units and vehicle onboard units.

According to Circumnav, the system will include a monitoring system that would detect anomalies in the probe data. This system can then alert Circumnav staff to emerging issues. This system is currently in development and was not evaluated.

5. Evaluation Methodology

This section describes how the performance measures described above were evaluated.

Obtain field vehicle-to-roadside and vehicle-to-vehicle communications testing data from Circumnav:

- The trial data provided by Circumnav should be selected randomly or be all-inclusive
- For each test run, the following attributes should be obtained:
  - Average vehicle speed
  - Vehicle type, antenna type and antenna placement
  - Location of road side unit and vehicle travel direction
  - Total size of data sent
  - Total duration for transmission and average transfer rate
  - Time of day
  - Build-number of system

Communicate with vendor regarding:

- Road side unit cost
- Road side unit maintenance
- Communication cost and specifications
- Data format
- Scalability issues
- Staffing requirements
- Anticipated size of a probe data packet that would be sent from vehicle onboard unit to road side unit
- Anticipated size of a 511 traffic data packet that would be sent by road side unit to the vehicle onboard unit
- Anticipated size of non-time-critical data updates, including map and yellow pages, that would be sent from road side unit to vehicle onboard unit
- Frequency of required data-intensive updates
- Anticipated probe data packet size sent between vehicles

6. Evaluation Results

Sample Sizes

- Number of vehicle-to-roadside communication tests analyzed in study – 20 trial runs
- Number of vehicle-to-vehicle communication tests analyzed in study – 84 trial runs
- Number of road side units tested – 5 locations
- Range of vehicle speeds tested – Unknown for vehicle-to-roadside communications, and for vehicle-to-vehicle communications the vehicle speed differential ranged from 14 mph to 133 mph.

Key Observations

Vehicle to Roadside Unit Communications

For vehicle-to-roadside communications, Circumnav provided limited but useful data. According to Circumnav, the performance of their initial vehicle-to-roadside communication results was strong that they did not log substantial amounts of this type of data. The data provided did not include attribute information of each data point. Therefore the vehicle-to-roadside communication assessment is highly dependent on Circumnav's self-evaluation.

According to the Circumnav data, the technology appeared capable of transmitting enough data between the vehicle and roadside unit to obtain probe data from the vehicle and send regional travel information to the vehicle. The average transfer consisted of over 2 MB data file and lasted 20 seconds. According to Circumnav, the Bay Area real-time traffic update file would only be 10-50 kb in size. Map or yellow pages updates would be of a similar size. Therefore, it appears that the transfer rate of approximately 100 kbps on average and the duration of transmission allow for successful operation of the system. The failure rate of transmissions can not be determined with the data provided by Circumnav. In addition, factors such as weather and topography that could reduce the functionality of the communications capabilities did not appear to be tested. According to the data provided by Circumnav, it appears that there is a significant amount of excess capability to handle some or all of these factors.

Vehicle to Vehicle Communications

More detailed and plentiful data was provided for vehicle-to-vehicle communications, allowing for a more in-depth evaluation. All 84 runs of data achieved a connection of at least 7 seconds with good (or better) connection quality. One run even achieved a good connection for 70 seconds. The connection quality classification of the connection is somewhat arbitrary and determined by Circumnav. The correlation between the connection quality and the transfer rate is not known. The time of day, size of data transfer, average transfer rate and vehicle type was not provided.

The average time with a continuous good connection was 20 seconds. The total time of connection, regardless of quality, ranged from 15 to 115 seconds, with an average of 41 seconds. Vehicles achieved a good connection at a vehicle separation distance ranging from 88 to 1362 meters. The average separating distance at which a good connection was reached was 526 meters. Some connection, regardless of quality, was first reached at a distance ranging from 163 to 2250 meters.

There appears to be significant variation in the distance[1] and quality of communications. As shown in Figure 3, the distance between the approaching vehicles has a significant effect on connection quality, and of course the distance at which communications is first reached determines the duration of connection.

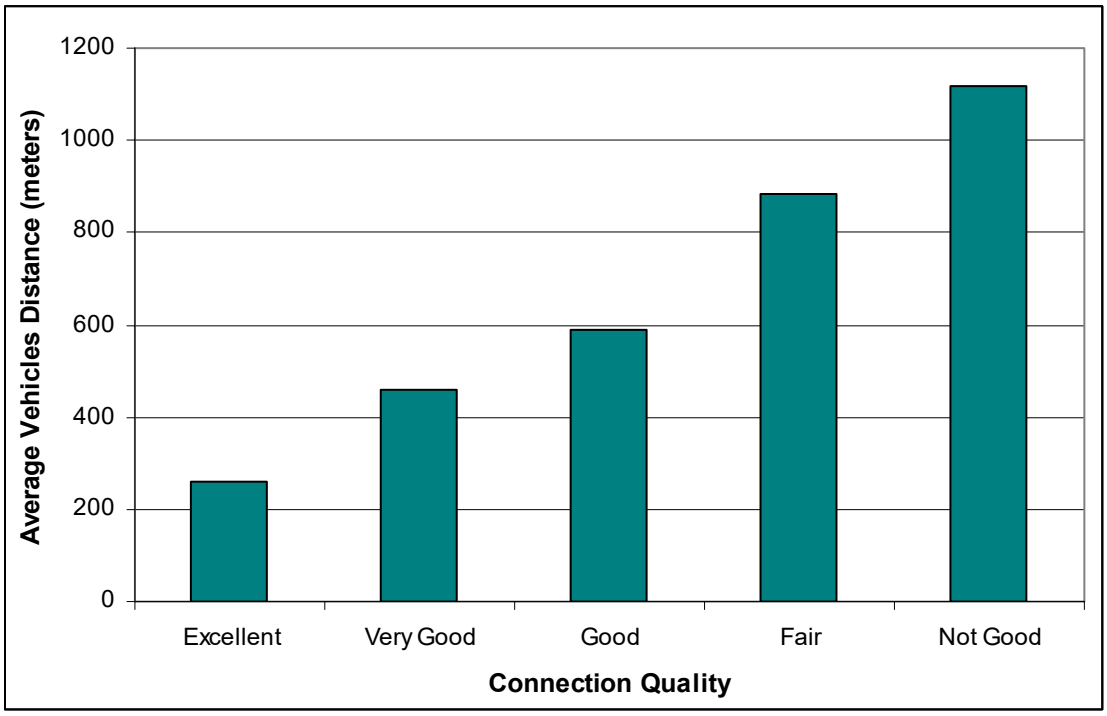

Figure 3: Average Vehicles Distance versus Connection Quality

As noted by Circumnav and by design, communications were significantly stronger when the vehicles were approaching each other than when they were increasing their separating distance. 46% of runs did not receive good connection at any point once the vehicles had passed each other. The average separation distance at which connection was lost after the vehicles had passed was only 76 meters.

Circumnav estimated the average speed of the vehicle during trial runs at 60 mph. The speed differential for communicating vehicles ranged from 14 to 133 mph without significant correlation with connection quality. The heading of a vehicle was not noted to

[1] Connection Distance Standard Deviation = 588 meters

make a significant impact on communications quality. However, trials were conducted on primarily straight stretches of roadway with heading differential (180 degrees for a straightaway) varied from 123 to 189 degrees.

Assuming the same file transfer rate provided by Circumnav for vehicle-to-roadside communications was achieved for vehicle-to-vehicle connections with a link quality of at least 50, the average connection included the transfer of approximately 2 MB. Assuming that only 10-50 kb of data would need to be transferred with each transmission, even the shortest good connection time experienced in the trials provided would have been able to transfer all required data.

7. Recommendation to Caltrans

PROS	CONS
Allows in-vehicle visual access to real-time traffic data	It requires a large number of probe vehicles and roadside devices to obtain valid data
Collects traffic data from probe vehicles, including information on major arterials	Recurring cellular connection costs to roadside units
Allows for map and yellow pages updates without user involvement	There may be a capacity limit of how many vehicles can communicate with each other and a single roadside device .
Allows data to be transmitted between passing cars and between vehicles and roadside devices	Topography, roadway curvature and speed differential may impact the communications performance shown in the trial data.
Can determine and distribute arterial roadway traffic conditions	Limited data available for vehicle-to-roadside communications.
Wi-Fi connections allow vehicle-to-roadside and vehicle-to-vehicle communication allows sharing of traffic information without incurring cellular data costs.	Currently the road side units are installed with call boxes. While call boxes are phasing out, feasible location for road side units may be difficult to determine.
New road construction and improvements information can be automatically determined and distributed by system	
Minimal installation cost and impact to existing roadway equipment.	

ITS Pilot Project Demonstration

Infotek
Evaluation

Prepared for
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FINAL

Prepared By
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ITS Pilot Project Evaluation

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Evaluation Summary

Vendor/Project – Infotek Wizard Intelligent Loop Detector Application (ILDA) Demonstration Project

Infotek, in cooperation with Cingular Wireless, deployed the Infotek Wizard Intelligent Loop Detector Application (ILDA) for monitoring freeway traffic using the roadway loop detectors. The Infotek Wizard ILDA is installed in Caltrans loop detector station cabinets, typically on top of the controller. It is connected to the existing loop detector cards and to a GSM antenna located on top of the cabinets or a small antenna connected directly to the Infotek Wizard ILDA inside the cabinet.

The InfoTek Wizard ILDA collects data from existing loop detectors and applies algorithms to the raw loop data to obtain individual vehicle real-time traffic data (stored in 30-second and 15-minute average "bins"). The post-processed results are relayed to Traffic Management Centers (TMC) via a GSM wireless network. (The InfoTek Wizard also has the capability of being hooked up to an Ethernet/ fiber network.)The device utilizes existing Caltrans algorithms as well as new algorithms developed for this demonstration.

The planned demonstration consists of deployments for dual-loop and single-loop configurations in District 4 (San Francisco Bay Area) and District 7 (Los Angeles County and Ventura County). These applications include the following:

- Dual-loop configuration (District 4): This application provides volume, speed, occupancy, and truck data from freeway loops in dual-loop configuration.
- Single-loop configuration (District 7): This application provides volume, occupancy, derived speed, and number of long vehicles from freeway loops in single-loop configuration. Speed is derived by using a District 7 algorithm (utilizing volume and occupancy inputs), and Infotek Wizard calculates vehicle length.

Delivery: Does demonstration satisfy the Vendor's stated objectives for Caltrans?

1. Does the Infotek Wizard ILDA collect and transmit the data items for dual-loop and single-loop configuration applications?

Dual-loop configuration (District 4):

• Volume data?	☒ YES	☐ NO	
• Speed data?	☒ YES	☐ NO	
• Occupancy data?	☒ YES	☐ NO	
• Long vehicle volume data?	☒ YES	☐ NO	

Single-loop configuration (District 7):

• Volume data?	☒ YES	☐ NO	☐ NOT VERIFIED
• Speed data?	☐ YES	☐ NO	☒ NOT VERIFIED

- Occupancy data? ☐ YES ☐ NO ☒ NOT VERIFIED
- Long vehicle volume data? ☒ YES ☐ NO ☐ NOT VERIFIED

The Infotek Wizard ILDA was installed in the cabinets of three dual-loop freeway monitoring stations in District 4 and three single-loop freeway monitoring stations in District 7. For the District 4 locations, Infotek provided volume, speed, occupancy, and classification data by lane for each deployment location. At the direction of District 7 TMC staff, the D7 Infotek evaluation focused on the count of long vehicles[1], and Infotek only provided lane volumes for both short and long vehicles.

2. Does the data collected and processed by the Infotek Wizard match Caltrans results and manual counts?

The Infotek data was compared to data provided by Caltrans and to manual counts. As per the direction of Caltrans District 4, the Caltrans data for the District 4 (dual-loop) locations was the Performance Management System (PeMS) website maintained by University of California, Berkeley for volume, speed, and occupancy data. Long vehicle counts were not compared since the PeMS long vehicle algorithm differs from that used by Caltrans District 4. It should be noted that PeMS and InfoTek have different approaches to arriving at their results—PeMS estimates their results based on 30 second average occupancy and total of 30 second volume, while InfoTek calculates individual vehicle volume, speed, occupancy, and length. For the District 7 (single loop) locations, the Caltrans data was provided by the Caltrans D7 Transportation Management Center. Manual count data for District 4 and District 7 was obtained by videotaping the traffic flow of the deployment locations for a 45-minute or 1 hour period.

<u>Comparison of Infotek data versus Caltrans</u>
As mentioned above, PeMS provided data for total volume, occupancy, and speed data for District 4 locations, but only long vehicle data was obtained for District 7 locations. Data (one-hour bins by lane) for the District 4 locations were collected over a two-day period, and over a three-day period for the District 7 locations. Table 1 through Table 4 below summarizes the percentage differences between the Infotek and Caltrans data for the various data types.

As shown in Table 1 and 3, Infotek's <u>total volume</u> data and <u>occupancy</u> data generally matched PeMS data on a daily basis for the I-80 Bay Bridge and the I-880 Union locations, but differed greatly when compared at an hourly level. Infotek's data most closely matched PeMS at the I-880 Union location; the hourly counts and occupancy were within 10% of Caltrans counts and the

[1] Defined as longer than 40 feet by District 7

average daily difference was within 3%. There were substantial differences between PeMS and Infotek data at the I-80 Ashby location, with PeMS data showing significantly lower results than the Infotek data[2].

As shown in Table 2, Infotek's speed data generally matched PeMS data on a daily basis, with greater deviation on an hourly basis. Again, Infotek's data from the I-880 Union location most closely matched PeMS data with an average daily difference of 4%.

As shown in Table 4, the Infotek's long vehicle data was in general agreement for the District 7 locations. In comparing Infotek's data with Caltrans District 7 TMC data, the average daily difference was 12.11% for all the locations.

Table 1: Percentage Differences of Total Volume data

Deployment Location	Range of hourly percentage differences	Average daily difference
District 4 locations only (dual-loop)		
I-80 Ashby Avenue	162% to 377%	228%*
I-80 Bay Bridge	-41% to 39%	9%
I-880 Union	-9% to 1%	3%
ALL D4 LOCATIONS	-41% to 377%	72%*

* The accuracy of Caltrans data is critical to the evaluation of Infotek data. Discrepancies between Caltrans data and Infotek data do not necessarily indicate issues with Infotek technology. The specific reason for discrepancies in each test location needs to be analyzed appropriately. In particular, the PeMS data at the I-80 Ashby Avenue location was much lower than Infotek's for total volume. This location may require further investigation to determine the source of the large difference. The large difference at the I-80 Ashby location may result in a disproportionate and inaccurate average difference for all District 4 locations.

Table 2: Percentage Differences of Speed data

Deployment Location	Range of hourly percentage differences	Average daily difference
District 4 locations only (dual-loop)		
I-80 Ashby Avenue	-28% to 60%	25%*
I-80 Bay Bridge	-53% to 40%	13%
I-880 Union	-21% to 36%	4%
ALL LOCATIONS	-53% to 60%	5%*

* The accuracy of Caltrans data is critical to the evaluation of Infotek data. Discrepancies between Caltrans data and Infotek data do not necessarily indicate issues with Infotek technology. The specific reason for discrepancies in each test location needs to be analyzed appropriately. The PeMS data at the I-80 Ashby Avenue location showed significantly greater differences in all evaluated criteria than the other District 4 locations. This location may require further investigation to determine the source of the large difference. The large difference at the I-80 Ashby location may result in a disproportionate and inaccurate average difference for all District 4 locations.

[2] It should be noted that the Infotek data closely matched the manual count results for this location (see Table 5).

Table 3: Percentage Differences of Occupancy data

Deployment Location	Range of hourly percentage differences	Average daily difference
District 4 locations only (dual-loop)		
I-80 Ashby Avenue*	39% to 119%	62%*
I-80 Bay Bridge	-78% to 365%	2%
I-880 Union	-9% to 3%	2%
ALL LOCATIONS	-78% to 365%	19%*

* The accuracy of Caltrans data is critical to the evaluation of Infotek data. Discrepancies between Caltrans data and Infotek data do not necessarily indicate issues with Infotek technology. The specific reason for discrepancies in each test location needs to be analyzed appropriately. The PeMS data at the I-80 Ashby Avenue location showed significantly greater differences in all evaluated criteria than the other District 4 locations. This location may require further investigation to determine the source of the large difference. The large difference at the I-80 Ashby location may result in a disproportionate and inaccurate average difference for all District 4 locations.

Table 4: Percentage Differences of Long Vehicle Counts data*

Deployment Location	Range of hourly percentage differences	Average daily difference
District 7 locations (single-loop)		
US-101 Downtown	6.68% to 14.42%	9.60%
SR-118 Simi Valley	14.87% to 16.31%	15.73%
I-210 Claremont	10.31% to 12.29%	11.00%
ALL D7 LOCATIONS	6.68% to 16.31%	12.11%

Comparison of Infotek data and manual counts

Infotek data for total volume and long vehicle counts data (District 7 only) was also compared with manual count results as an independent check. Table 5 summarizes the comparison of total vehicle count, and Table 6 summarizes the comparison of long vehicle volumes. As shown in Table 5, Infotek's total volume data matched very closely with the manual counts, being within 1% at three locations and within 6.16% at all locations. As shown in Table 6, Infotek's long vehicle count data generally matched the manual counts, being within 10% at two locations and within 15.94% at all locations.

Table 5: Percentage Differences of Total Volume data (Infotek vs. Manual Counts)

Deployment Location	Evaluation Date, Time period	Percent difference
District 4 locations (dual-loop)		
I-80 Ashby Avenue WB	11/1, 3:45-4:30	0.97%
I-880 Union NB	11/1,11:45-12:45	2.65%
District 7 locations (single-loop)		
US-101 Downtown NB	5/17,11:30-11:45	0.28%
US-101 Downtown SB	5/17,11:30-11:45	0.89%
SR-118 Simi Valley	5/17, 4:00-4:15	1.71%
Interstate 210	5/18, 4:00-4:15	6.16%

Table 6: Percentage Differences of Long Vehicle Counts data (Infotek vs. Manual Counts)

Deployment Location	Evaluation Date, Time period	Percent difference
District 7 locations (single-loop)		
US-101 Downtown NB	5/17,11:15-12:15	7.73%
US-101 Downtown SB	5/17,11:15-12:15	15.94%
SR-118 Simi Valley	5/17, 3:45-4:30	12.33%
Interstate 210	5/18, 3:45-4:30	6.06%

Key Observations

The Infotek Wizard ILDA provides total volume, speed, occupancy and long vehicle count data for dual-loop and single-loop configurations of freeway detector stations. In comparing the Infotek results to the reference data (PeMS or Caltrans District 7 TMC), the data can vary substantially on an hourly level, but these differences appear to average out so that the daily results are in general agreement. The differences appear to be influenced by deployment location, rather than by time of day or traffic-volume relationships. These differences may indicate the need for additional fine-turning at these locations. In some cases, the data also shows smaller variances for the middle lanes and greater variances for the outer lanes; this may indicate that speed (or the variety in the sample speeds) may be a factor in either the Infotek or reference data.

A limited comparison of Infotek total volume and long vehicle count data with manual counts showed close agreement between the two for total volume, but greater differences for the long vehicle count. This could indicate that additional fine-tuning could increase performance.

Discussion with Caltrans staff indicated significant interest in some of the other features of the device that were not explicitly included in our evaluation. These features can be accessed through the cellular network, reducing travel time by maintenance and engineering staff to the monitoring stations. These features include the following:

- ***Loop diagnostic tools*** **– These allow the user to check whether loops are working and if they are configured in the correct order (dual loop configuration).**
- ***Controller interface*** **– The Wizard has a serial interface that could be connected to the 170/2070 controller for remote access.**
- ***Remote Cabinet reset*** **– The Wizard can be set-up and wired to allow Caltrans staff to reset the cabinet or detector rack from the office rather than physically going out to the field.**

Recommendation to Caltrans

PROS	CONS
Total daily volume data closely matches manual counts.	Requires field calibration of Caltrans detector cards at each deployment location.
Can provide vehicle classification (length data) from single-loop and dual-loop detector configurations.	Accuracy of results may vary based on variance in volume or speed.
Provides cellular communications link to field controllers. Useful for items like cabinet and detector rack remote reset.	Recurring cellular communications costs[3].
Includes loop diagnostic tools	
Less expensive than 170/2070 controller	
Device is programmable and format of data can be easily changed based on user needs.	

[3] Typical Caltrans dial-up and leased-line communications methods also have recurring costs.

Evaluation Details

1. Delivery

Vendor's Stated Objective in Caltrans Contract

- *Provide post-processed real-time traffic data from loop detection stations in dual-loop and single-loop configuration.*
- *Dual-loop configuration (District 4): Provide volume, speed, occupancy, classification (length), 30 seconds polled and 15 minutes average bin.*
- *Single-loop configuration (District 7): Single loop detection of long vehicles. Wizard will monitor a single loop to capture volume and occupancy per lane. The Wizard will then apply an algorithm from District 7 that derives speed. From volume, occupancy, and derived speed, an algorithm will be developed to determine the number of long vehicles. Volume, occupancy, derived speed, and number of long vehicle data will then be relayed to District 7 and stored into a database.*

Additional Assertions and long-term goals

- *Implement algorithms that add value to the raw loop data beyond anything being practiced today.*
- *Size of post-processed information is small compared to raw loop data and therefore easier/faster to transmit on wireless and wired networks.*
- *Replace and/or complement 170/ 2070 controllers. Provide expert system and logic in cabinet that can make decisions based on changing traffic conditions, such as ramp metering. Reduce data collection and processing costs to one-half or one-third compared to 170/2070 controllers.*

2. Project Specifics

Deployment Date(s) and Time(s)	Evaluation Date(s) and Time(s) *Include weather conditions*
<u>District 4 (San Francisco Bay Area)</u> • Deployed Spring 2006 and calibration completed in Fall 2006. <u>District 7 (Los Angeles & Ventura Counties)</u> • Deployed in Spring 2006, with calibration completed in April 2006.	<u>District 4 (San Francisco Bay Area)</u> • November 1-2, 2006. <u>District 7 (Los Angeles & Ventura Counties)</u> • May 16-18, 2006
Deployment Location(s) ***Include diagram or map if applicable***	**Evaluation Location(s)** ***Include diagram or map if applicable***
<u>District 4 (San Francisco Bay Area)</u> • Interstate 80 at Ashby Avenue (Berkeley) • Interstate 80 at San Francisco Bay Bridge (Oakland) • Interstate 880 south of 7th Street (Oakland) <u>District 7 (Los Angeles & Ventura Counties)</u> • Route 101 at Edgeware Road (Downtown Los Angeles) • Route 118 east of Tapo Canyon Road (Simi Valley) • Interstate 210 west of Baseline Road (Claremont)	<u>District 4 (San Francisco Bay Area)</u> • Same as deployment locations <u>District 7 (Los Angeles & Ventura Counties)</u> • Same as deployment locations

3. Technology

3.1 Technology or System Description

The Infotek Wizard ILDA is a GSM based GPRS/EDGE modem (certified by Cingular Wireless) with an Intelligent Loop Detector Application (ILDA) program installed. The Wizard operates as an external wireless modem with serial connectivity offering a cost effective alternative to dial-up and leased lines. According to the vendor, Cingular offers a flexible data rate plan that reduces costs by allowing users to stay connected without any airtime charges until real data is transferred. The Wizard is Java-programmable with 32 digital inputs and 8 digital outputs, and can support up to 28 loops (14 loops in dual-loop configuration). The device summarizes volume, occupancy, and long vehicle counts into typical 15-minute bins. The device can be configured to work with existing polling systems. Data collector software is compatible with Oracle, MS Access, and MS SQL.

The Infotek Wizard connects directly to loop detector outputs using standard detector output cables equipped with diodes to allow coexistence with 170/2070/NEMA and other controllers with no interference. A GSM antenna mounts on top of traffic cabinets for wireless connectivity A small GSM antenna that connects directly to the InfoTek Wizard inside the cabinet can also be used. The Infotek Wizard obtains power from a power adapter plugged into the Controller PDA (standard voltage).

The ILDA is an application of the Wizard that collects traffic data from loop detectors and applies algorithms to the collected data in real-time. The post-processed results are relayed to traffic management centers via cellular network. The vendor claims that custom applications can be developed using Java to support real-time ITS applications, such as alarms to provide real-time alert notification when special traffic conditions are detected (e.g. warning a large truck that it is speeding by flashing a message on a VMS, or alerting traffic center or drivers when traffic suddenly slows) or to integrate real-time data to ATMS, live maps, and web-based applications.

3.2 Previous Evaluations (including vendor's own) and/or Similar Technology Deployments

According to the Vendor, the Oregon Department of Transportation (ODOT) compared the volume count by lane outputs between a standard PEEK controller station and the Infotek Wizard ILDA for a test site from September 28, 2005 through October 5, 2005. In a daily comparison by lane, the Infotek Wizard ILDA matched the PEEK outputs within 1%. This claim was not independently evaluated.

According to the Vendor, District 10 has deployed the Infotek Wizard to take advantage of the "always-on" cellular communications capabilities as a replacement for their copper networks and dial-up connections. The ILDA features are not currently being used in District 10. This claim was not independently evaluated.

4. Performance Measures

Performance measures for this project are defined here and divided into different categories for evaluation and discussion: Quantitative, Qualitative, and Other Performance Factors. Quantitative measures cover the aspects of performance that can be reflected with any available performance data. Qualitative measures cover the aspects of performance that has equal significance but cannot be compared with numbers. Other performance factors discuss issues not addressed by quantitative and qualitative measures but may influence the technology's future deployment.

Definition of Performance Measures

The performance measures for these deployments focus on the data being provided by the Wizard ILDA. The demonstration plan includes two applications of the Infotek Wizard ILDA. In the first deployment (District 4 dual-loop configuration), the Wizard provided volume, speed, and occupancy data. In the second deployment (District 7 single-loop deployment), the Wizard provided and count of long vehicles (greater than 40 feet in length).

The Infotek data was compared to data provided by Caltrans and to manual counts. As per the direction of Caltrans District 4, the Caltrans data for the District 4 (dual-loop) locations was the Performance Management System (PeMS) website maintained by University of California, Berkeley for volume, speed, and occupancy data. Long vehicle counts were not compared since the PeMS long vehicle algorithm differs from that used by Caltrans District 4. It should be noted that PeMS and InfoTek have different approaches to arriving at their results—PeMS estimates their results based on 30 second average occupancy and total of 30 second volume, while InfoTek calculates individual vehicle volume, speed, occupancy, and length. For the District 7 (single loop) locations, the Caltrans data was provided by the Caltrans D7 Transportation Management Center. Manual count data was obtained by videotaping the traffic flow of the deployment locations for a 45-minute or 1 hour period.

4.1 Quantitative Outputs

The Infotek Wizard ILDA will be quantitatively evaluated by comparing data processed by the Infotek Wizard ILDA to baseline data collected and processed by a combination of manual observation and by existing loop detector stations. The existing loop polling system should remain in place and operational throughout the entire test period for both single-loop and dual-loop applications.

Accuracy

For Single Loop Configuration (District 7):

At the direction of District 7, this evaluation focused on the count of long vehicles (vehicle length greater than 40 feet) and not on total volume, occupancy or derived speed. Caltrans District 7 provided long vehicle counts for three locations over a consecutive three-day period.

1. Is volume data accurate compared to baseline data?

   ☐ YES ☐ NO ☒ NOT EVALUATED

   Total volume data was not provided by District 7. Infotek provided short vehicle volumes and long vehicle volumes (which were summed up to derive total volumes.)

2. Is speed data accurate compared to baseline data?

   ☐ YES ☐ NO ☒ NOT EVALUATED

   Comparison not included in District 7 evaluation.

3. Is occupancy data accurate compared to baseline data?

   ☐ YES ☐ NO ☒ NOT EVALUATED

   Comparison not included in District 7 evaluation.

4. Is vehicle classification data accurate compared to the baseline data?

   ☒ YES ☐ NO ☐ NOT EVALUATED

   The Infotek count of long vehicles was generally in agreement when compared against Caltrans TMC results and manual count results. Comparison with Caltrans TMC results were done over a period of three consecutive days (one-hour bins). The range of daily percentage differences range from 6.68% to 16.31% (average daily difference of 12.11%). Tables summarizing the daily variance (average and range) between the ILDA results and the Caltrans TMC results and the hourly percentage variances are included in the Evaluation Results section.

   Manual counts were conducted for a "spot" sample 45-minute or 1-hour period for each deployment location and compared to the ILDA data. The percentage difference ranged from 6% to 16% with an average percentage difference of 10.5%. Tables summarizing the percentage difference of the total ILDA counts are included in the Evaluation Results section.

5. Does the accuracy of the data decrease as traffic volumes increase or as speeds decrease? ☐ YES ☐ NO ☒ UNCERTAIN

There did not appear to be a time of day or traffic volume relationship between the percentage differences of the Caltrans and ILDA data. The deployment location appears to be a factor in the percentage differences-- this could indicate the need for additional calibration at specific locations. In addition, the variances appear to be smaller for the middle lanes and greater for the outer lanes. It is uncertain whether this is attributable to the speed or driving characteristics.

6. What is the approximate speed that the data becomes inaccurate?
   Uncertain if speed is a factor. See Question 5 above.

7. What is the approximate volume that the data becomes inaccurate?
   Uncertain if volume is a factor. See Question 5 above.

For Dual-Loop Configuration (District 4):

At the direction of Caltrans District 4, PeMS was used as the reference data for volume, speed, and occupancy at the deployment locations and there was no comparison for the long vehicle (truck) volume results. The Infotek Wizard ILDA has been installed in the cabinets of three dual-loop freeway monitoring stations.

8. Is volume data accurate compared to baseline data?

   ☒ YES ☐ NO ☐ NOT EVALUATED

   The results for I-880 and I-80 Bay Bridge locations indicates that the Infotek can provide accurate volume data compared to the baseline data. There substantial differences for the I-80 Ashby location.

9. Is speed data accurate compared to baseline data?

   ☐ YES ☒ NO ☐ NOT EVALUATED

   There were moderate discrepancies between Infotek data and baseline data for speed measurements with daily differences of within +/- 13% for the I-80 Bay Bridge location and the I-880 location. The I-80 Ashby Avenue location had daily differences of 25%. The Infotek data generally reflects the same changing pattern of average speed with time of day. The Infotek speed data curve is flatter than that of the baseline data, which may indicate that the algorithm used by Infotek to calculate speed has probably dismissed data with extreme high or low values. This approach could minimize the disproportionate impact of sample outliers on the average result.

10. Is occupancy data accurate compared to baseline data?

☒ YES ☐ NO ☐ NOT EVALUATED

Occupancy data provided by Infotek is very accurate compared to the baseline (PeMS) data, with daily differences around -2% (not including the I-80 Ashby Avenue location).

11. Is vehicle classification data accurate compared to the baseline data?

☐ YES ☐ NO ☒ NOT EVALUATED

PeMS algorithm for long vehicle differs from that being used by District 4 TMC. At the direction of District 4, this data was not compared .

12. Does the accuracy of the data decrease as traffic volumes increase or as speeds decrease? ☐ YES ☐ NO ☒ UNCERTAIN

Volume and occupancy data has some variance between Infotek and baseline (PeMS) data .

13. What is the approximate speed that the data becomes inaccurate?
Unknown. See Question 12 above.

14. What is the approximate volume that the data becomes inaccurate?
Unknown. See Question 12 above.

Reliability

For Single Loop Configuration (District 7):

15. How many times in a 24-hour period did the communications fail to transmit data?

There were no communication/transmission failures during the 72-hour evaluation period.

16. What is the average time that a unit is not communicating in a 24 hour period?

Devices were always communicating.

17. Did any devices require replacement/repair during the evaluation? ☐ YES ☒ NO

For Dual-Loop Configuration (District 4):

18. How many times in a 24-hour period did the communications fail to transmit data?
    None

19. What is the average time that a unit is not communicating in a 24 hour period?
    None

20. Did any devices require replacement/repair during the evaluation?
    ☐ YES ☒ NO ☐ NOT DEPLOYED

21. If so, how many and what was the amount of time before the replacement or repair and the cost of the replacement/repair?
    No replacement/repair needed during the test.

Productivity

For Single Loop Configuration (District 7):

22. What is the lag/latency between the time data is measured and when it is transmitted to traffic control centers?
    The maximum lag in these applications was 15 minutes. As directed by the Districts, the Infotek Wizard collects data from the loop detector cards every 30 seconds and transmits it over the cellular network every 15 minutes. InfoTek Wizard can be set-up to collect and relay information as per the individual needs of the location agency.

23. Are there any other applications for this device that are not evaluated?
    The Wizard has several features that could be used to improve Caltrans staff productivity. These features can be accessed through the cellular network, reducing travel time by maintenance and engineering staff to the monitoring stations. These features include the following:

    - ***Loop diagnostic tools*** **– These allow the user to check whether loops are working and if they are configured in the correct order (dual loop configuration).**
    - ***Controller interface*** **– The Wizard has a serial interface that could be connected to the 170/2070 controller for remote access.**
    - ***Remote Cabinet reset*** **– The Wizard can be set-up and wired to allow Caltrans staff to reset the cabinet or detector rack from the office rather than physically going out to the field.**

According to the Vendor, the programmable nature of the Wizard ILDA allows for the collected and processed data to be formatted to meet various Caltrans standard reports (e.g. PEMS). Such a feature could reduce the time that Caltrans staff would need to spend on data manipulation. This could not be confirmed as part of this evaluation.

For Dual-Loop Configuration (District 4):

24. What is the lag/latency between the time data is measured and when it is transmitted to traffic control centers?
    See Question 22 (above).

25. Are there any other applications for this device that are not evaluated?
    See Question 23 (above).

4.2 Qualitative Outputs

Accuracy

For Single Loop Configuration (District 7):

26. How did a range of speeds affect the accuracy of the device?
    Data accuracy did not change with speed.

27. Did an incident and the resulting disruption to traffic have an effect on the accuracy of the data?
    No incidents were recorded during the evaluation period.

For Dual-Loop Configuration (District 4):

28. How did a range of speeds affect the accuracy of the device?
    Data accuracy did not change with speed.

29. Did an incident and the resulting disruption to traffic have an effect on the accuracy of the data?
    No incidents were recorded during the evaluation period.

Reliability

30. Was poor weather encountered during the evaluation? ☐ YES ☒ NO

Productivity

31. Was traffic disrupted during installation? ☐ YES ☒ NO

32. Does the system integrate with and provide a benefit to the 511 network? ☐ YES ☒ NO

The deployment application did not include direct integration to the 511 network. Although this technology uses the same loop detectors that Caltrans uses to collect data, it could serve as another source of data validation for the 511 network.

33. Is data transmittal suitable both for historical and ITS (real-time) applications? ☒ YES ☐ NO

The data format matches Caltrans current format and can be modified as requested by Caltrans. Data transmission speeds over the cellular network are suitable for real-time ITS applications.

34. Can the device provide additional information such as density, lane information, or minimum and maximum speeds?

According to the vendor, the device can provide density, lane information, minimum and maximum speeds. The device can be programmed to calculate other information from the loop detector inputs, either in real-time or based on archived data. The device can store approximately one month of data. This was not verified as part of this evaluation.

35. How do these performance measures relate to Caltrans' 9 Performance Measures?

Caltrans' performance measures are used to assess the operations of multi-modal transportation systems in order to create a more accountable framework for decision making. The following table relates the project performance measures against the Caltrans performance measures.

	Caltrans 9 Performance Measures								
	Mobility/Accessibility /Reliability	Productivity	System Preservation	Safety	Environmental Quality	Coordinated Transportation and Land Use	Economic Development	Return on Investment	Equity
Outputs Measured									
Accuracy	✓								
Reliability	✓								
Productivity	✓	✓					✓	✓	

4.3 Performance Factors

Scalability and Sensitivity

36. Is a minimum deployment needed (e.g., would increasing the deployment by a certain amount lead to an increase in accuracy)?

The deployment application is focused on single loop station and does not communicate with other stations. A minimum deployment is not needed to increase its accuracy.

37. Does the system integrate easily with existing loops? ☒ YES ☐ NO

38. How easily does it integrate with existing technologies?

The Wizard ILDA connects directly to existing loop detector cards and can operate in parallel with the existing 170/2070 controller at freeway count stations. The Wizard ILDA could also be used as a cellular modem for the existing 170/2070 controllers as a dual system being a modem when needed

and collecting traffic data when not used as a modem, replacing the existing Caltrans AirLink modems. (According to the Vendor, there is some interruption of the Wizard ILDA data collection features when it is used as a modem to the controller.)

39. Describe integration issues that were encountered.

No integration issues were reported as part of the District 7 deployment. Some network communications issues were encountered during the District 4 deployment that affected the calibration and collection of data. Much of this was outside the control of Infotek and Cingular.

40. Is the Infotek device compatible with detection technologies other than loops (e.g. microwave, video detection, etc.)

The evaluated deployment utilized loop detection technology. The Wizard ILDA has not been deployed with other detection technology at this time. Whether the Wizard could be configured to work with other detection technology would depend on the inputs from that technology—the Wizard interfaces include one RS-232 serial port, 32 digital input channels, 8 digital output channels, and 3 analog inputs/outputs.

Safety

41. Can the equipment be used to detect and report real-time incidents?

☐ YES ☐ NO ☒ NOT VERIFIED

Vendor is working with Caltrans District 10 to test a fog and slow traffic alert system. This information was not verified or evaluated as part of this evaluation.

Staffing and Training

42. Can Caltrans maintain and/or install the device? ☒ YES ☐ NO

43. Document the level of effort required to install and calibrate the device.

According to the vendor, the Wizard ILDA can be installed in about an hour by Caltrans staff for a typical working installation. It takes about 30 minutes to install a "hockey puck" cellular antenna to the top of the cabinet and connect the Wizard to the loop detector cards and cellular antenna. (As per the vendor, the new versions of the Wizard have antenna with enough gain that the antenna can remain inside the cabinet—this would eliminate needing to drill a hole through the cabinet and mounting an antenna.) It takes another 30-45 minutes to configure and calibrate the Caltrans detector cards (with the help of the vendor). This configuration estimate assumes that all loops and cards are working and that the dual-loops (if used) are installed in a standard 20-foot offset configuration.

A field visit to configure a District 4 location took 45 minutes. This included using a radar gun to obtain vehicle speeds. For this visit, it appeared that the loop offset was 20 feet, so additional adjustments to the Wizard algorithm for speed were not required.

Cost

44. What is the unit cost of the device? What are the recurring costs?

The device cost of the Infotek Wizard depends on which loop configuration is used. The dual-loop Wizard costs $1,500 per unit and the single-loop version costs $2,000. Caltrans would typically get a discounted price of $1,200 for the dual-loop Wizard and $1,700 for the single-loop Wizard. The two versions of the devices are physically the same, but have different firmware installed for the application.

Once the unit has been installed, the recurring costs include minimal electricity to power the unit and cellular backhaul service estimated to be $30-$40 per month. The unit can also work with an Ethernet and fiber system, which would eliminate recurring communication costs.

For a cost comparison against traffic signal controllers, the list price for 2070 controllers is between $3,000 to $4,000 each, and between $1,000 and $1,200 each for 170 controllers, depending whether the controller firmware is included and which hardware accessories are installed. Firmware costs range between $800 to $1,200 per unit and communication cards add around $250 per unit. There are typically some discounts in price for volume ordering. Caltrans has a volume contract with controller manufacturers that prices base 2070 controllers and 170 controllers at approximately $1500 and $700 each, respectively. These controllers do not include firmware (Caltrans installs their program) or communication cards.

5. Evaluation Methodology

How were the performance measures described above evaluated?

These performance measures were evaluated using the following steps.

A. System Research
- **Obtain equipment technical information (including cost) and deployment requirements from vendor**
- **Obtain evaluation results from past deployments from vendor (if any)**

B. System Installation
- **Coordinate with Infotek, District 4 and District 7 staff to confirm deployment locations**
- **Attend installation of Infotek equipment (if possible).**
- **Attend calibration of Infotek equipment with existing loops (if possible)**

C. Evaluation Methodology
- **Coordination with Infotek, Caltrans District 4 and District 7 staff regarding evaluation period and data format.**

D. Data Collection
- **Collect evaluation data during evaluation period:**
  - **Infotek**
  - **Caltrans District 4 and District 7**
  - **Manual Counts**

E. Data Evaluation
- **Compare Infotek data with Caltrans and manual count data**

6. Evaluation Results

The Infotek Wizard ILDA demonstration plan included a total of six deployments at existing Caltrans freeway loop monitoring stations. Three deployments were in Caltrans District 4 (San Francisco Bay Area) and another three deployments were in Caltrans District 7 (Los Angeles and Ventura Counties). The District 4 locations used dual-loop configurations, while the District 7 location used single-loop configurations. The Infotek equipment was installed at the following locations in District 4:

- Interstate 80 at Ashby Avenue (Berkeley)
- Interstate 80 at San Francisco Bay Bridge (Oakland)
- Interstate 880 south of 7th Street (Oakland)

The Infotek equipment was installed at the following locations in District 7:

- Route 101 at Edgeware Road (Downtown Los Angeles)
- Route 118 east of Tapo Canyon Road (Simi Valley)
- Interstate 210 west of Baseline Road (Claremont)

Evaluator staff did not attend any of the installations in District 4 or District 7. Evaluator staff attended the calibration of the Interstate 880 location in District 4.

Data Collection

The Infotek data was compared to data provided by Caltrans and to manual counts. As per the direction of Caltrans District 4, the Caltrans data for the District 4 (dual-loop) locations was the Performance Management System (PeMS) website maintained by University of California, Berkeley. For the District 7 (single loop) locations, the Caltrans data was provided by the Caltrans D7 Transportation Management Center. Manual count data was obtained by videotaping the traffic flow of the deployment location for a 45-minute and 1 hour period.

District 4 Locations

For the District 4 locations, total volume, speed, and occupancy data was collected and compared. Evaluations were conducted for a continuous 48-hour period from November 1 to November 2, 2006 (Wednesday and Thursday). Manual counts for a "spot" 1-hour sample were gathered by video at two of the deployment locations on November 1, 2006.[4] Data was gathered and compared by location, lane, and hour for each day. The following figures are provided below as samples. **Figure 1** through **Figure 3** show hourly Infotek and PeMS data in the eastbound direction of the I-880 location for 11/1/06.

[4] No counts were conducted for the Bay Bridge location (both directions) and southbound I-880 location due to lack of suitable observation point. Planned manual counts for eastbound I-80 at Ashby was not collected due to rain.

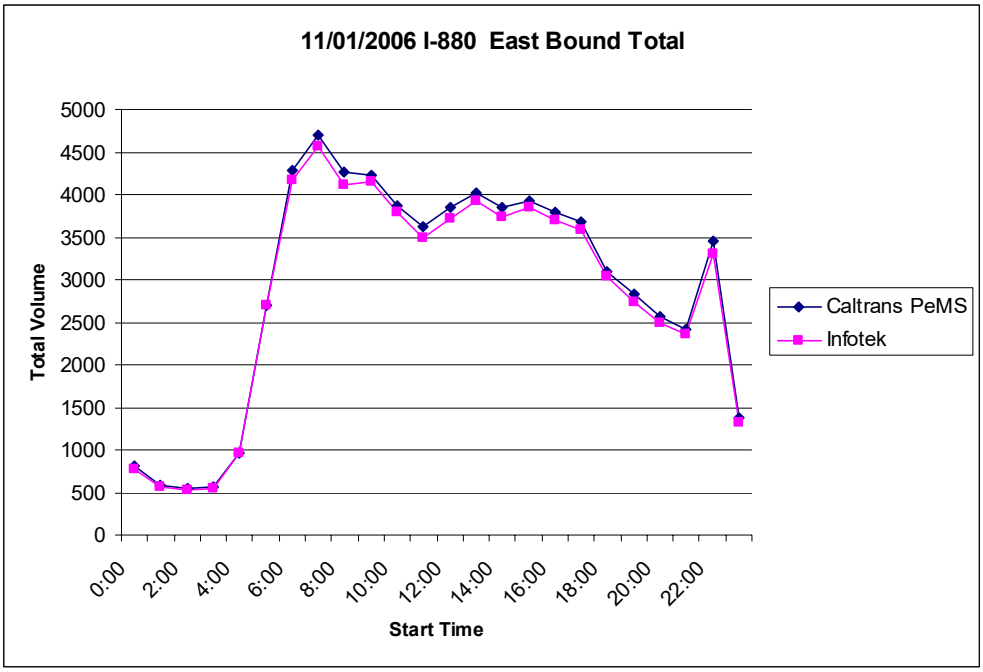


Figure 1: Infotek and Caltrans Total Vehicle Volume on East Bound I-880 Union

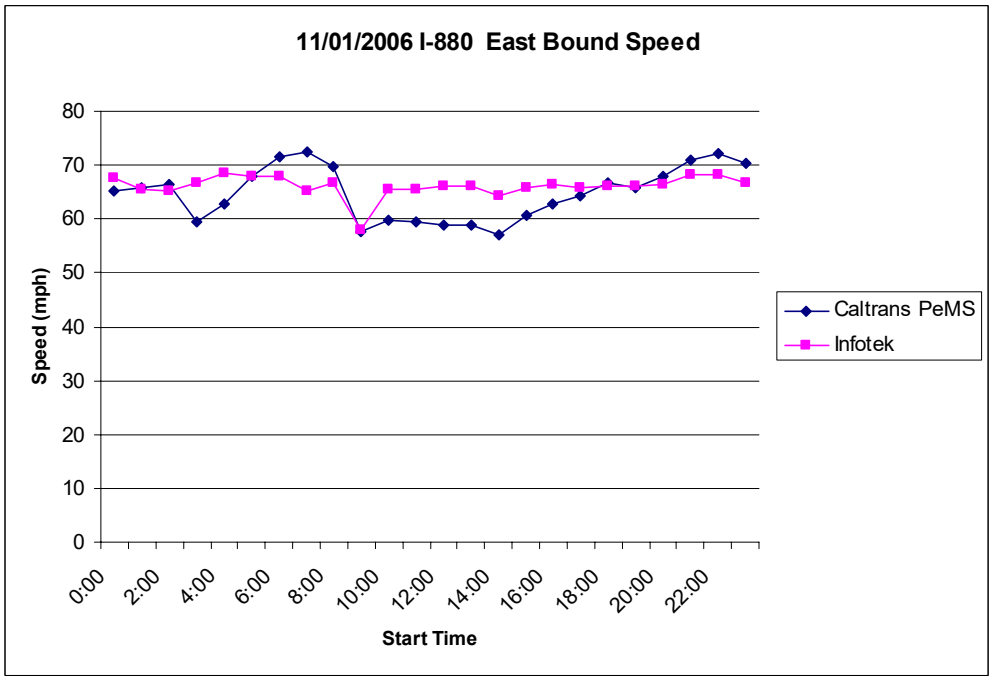


Figure 2: Infotek and Caltrans Speed on East Bound I-880 Union

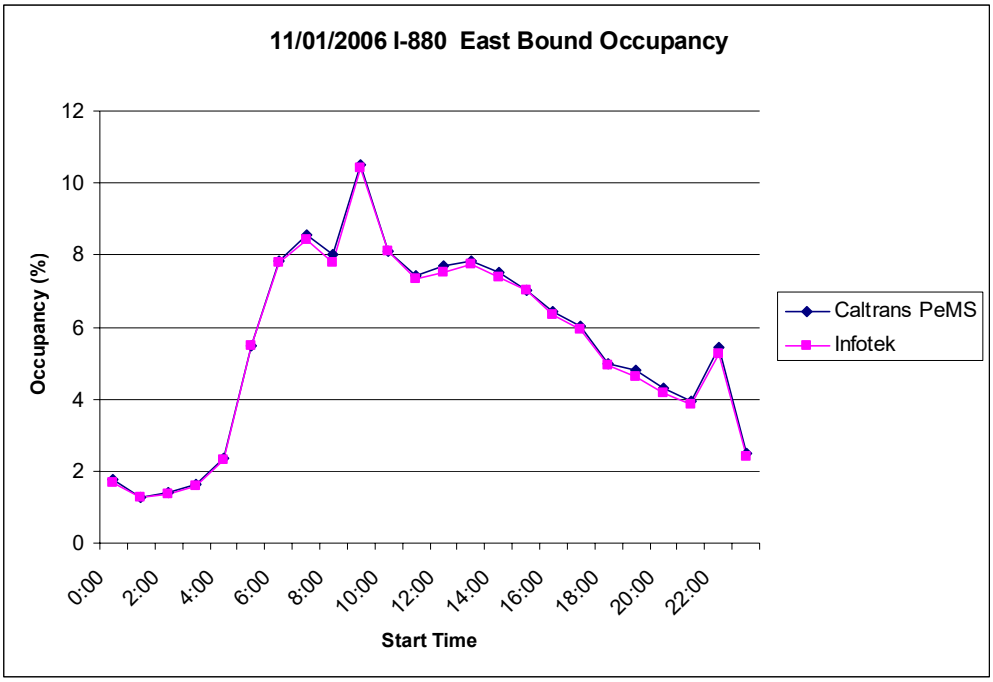


Figure 3: Infotek and Caltrans Occupancy on East Bound I-880 Union

District 7 locations

As per the direction of District 7 staff, the evaluation focused on the count of long vehicles (defined as greater than 40 feet). For the District 7 locations, evaluations were conducted for a continuous 72-hour period from May 16-18, 2006 (Monday through Wednesday). Manual counts for a "spot" sample 45-minute and 1-hour period were gathered by video for each deployment location. Data was gathered and compared by location, lane, and hour for each day. The following figure below is provided as a sample. **Figure 4** compare the total results for the Infotek and Caltrans results for the NB 101 location on May 17, 2006.

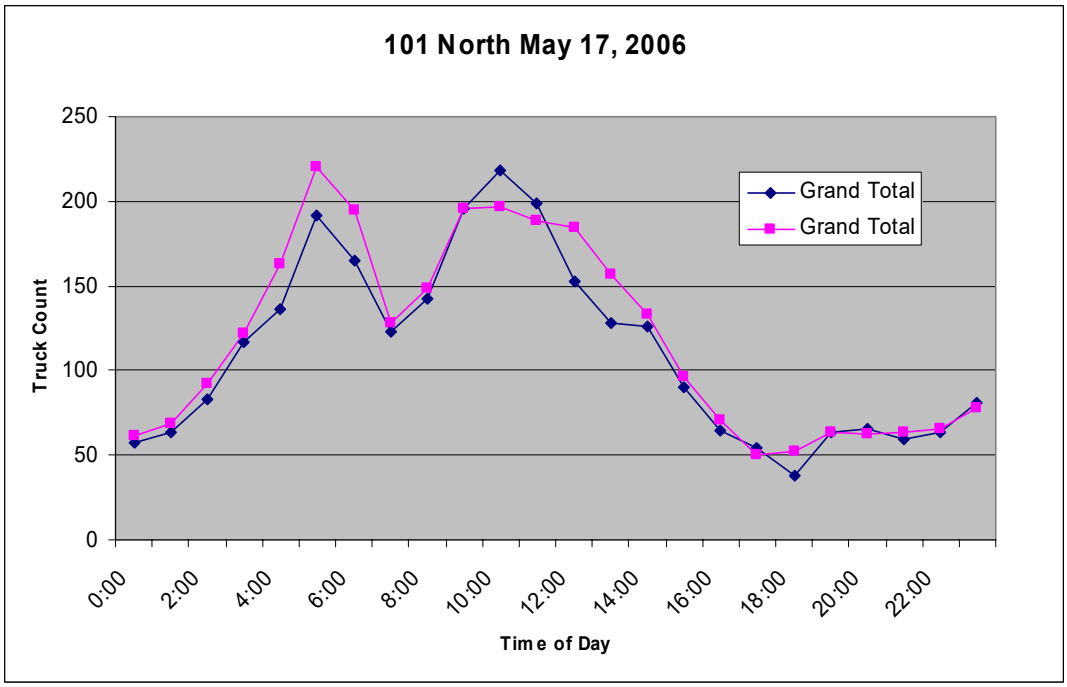


Figure 4: Infotek and Caltrans Truck Counts on 5/17/2006 on US-101 northbound (total, all lanes)

Key Observations

The results of comparing the Infotek data with the Caltrans data and spot manual counts are summarized below.

District 4 locations

Comparison of Infotek data and Caltrans (PeMS) data

Table 7 through **Table 9** summarize the percent differences between Infotek and PeMS data on an hourly and a daily basis for total volume, speed, and occupancy, data. **Table 7** shows that in the I-880 deployment, the Wizard volume data is very close to that of Caltrans with average daily variance of only 3%. **Table 8** shows that in the I-880 deployment, the Wizard occupancy data is generally consistent to that of Caltrans with average daily variance of only 2%. **Table 9** shows that in the I-880 deployment, the Wizard speed data is generally consistent to that of Caltrans with average daily difference of only 4%.

Table 7: Percentage Differences of Total Vehicle Volume

Deployment Location	Range of hourly percentage differences	Average daily difference
I-80 Ashby Avenue	162% to 377%	228%
I-80 Bay Bridge	-41% to 39%	9%
I-880 Union	-9% to 1%	3%
ALL LOCATIONS	-41% to 377%	72%

Table 8: Percentage Differences of Occupancy

Deployment Location	Range of houly percentage differences	Average daily difference
I-80 Ashby Avenue	39% to 119%	62%
I-80 Bay Bridge	-78% to 365%	2%
I-880 Union	-9% to 3%	2%
ALL LOCATIONS	-78% to 365%	19%

Table 9: Percentage Differences of Speed

Deployment Location	Range of hourly percentage differences	Average daily difference
I-80 Ashby Avenue	-28% to 60%	25%
I-80 Bay Bridge	-53% to 40%	13%
I-880 Union	-21% to 36%	4%
ALL LOCATIONS	-53% to 60%	5%

Table 10 through **Table 12** summarizes the deviation in the hourly data between Infotek and the PeMS samples for the various data types. **Table 10** shows that in the I-880 deployment, 88% of the Wizard volume data is within 5% of Caltrans and 100% of the Wizard volume data is within 10% of Caltrans. **Table 11** shows that in the I-880 deployment, speed data has moderate discrepancies between Wizard data and Caltrans data. 46% of the Wizard volume data is within 5% difference range to that of Caltrans and 88% of the Wizard volume data is within 20% difference range to that of Caltrans. **Table 12** shows that in the I-880 deployment, 92% of the Wizard occupancy data is within 5% difference range to that of Caltrans and 100% of the Wizard volume data is within 10% difference range to that of Caltrans. The differences in the daily and hourly results could be due to sample time synchronization factors.

Table 10: Infotek deviation from Caltrans (hourly samples) for Total Vehicle Volume

Deployment Location	Total samples	Samples +/- 5% (samples)	Samples +/- 10% (samples)	Samples +/- 20% (samples)
I-80 Ashby Avenue	48	0% (0)	2% (1)	2% (1)
I-80 Bay Bridge	48	27% (13)	50% (24)	79% (38)
I-880 Union	48	88% (42)	100% (48)	100% (48)
ALL LOCATIONS	144	38% (55)	51% (73)	60% (87)

Table 11: Infotek deviation from Caltrans (hourly samples) for Occupancy

Deployment Location	Total samples	Samples +/- 5% (samples)	Samples +/- 10% (samples)	Samples +/- 20% (samples)
I-80 Ashby Avenue	48	0% (0)	2% (1)	2% (1)
I-80 Bay Bridge	48	96% (46)	100% (48)	100% (48)
I-880 Union	48	92% (44)	100% (48)	100% (48)
ALL LOCATIONS	144	38% (55)	51% (73)	60% (87)

Table 12: Infotek deviation from Caltrans (hourly samples) for Speed

Deployment Location	Total samples	Samples +/- 5% (samples)	Samples +/- 10% (samples)	Samples +/- 20% (samples)
I-80 Ashby Avenue	48	2% (1)	6% (3)	44% (21)
I-80 Bay Bridge	48	0% (0)	10% (5)	96% (46)
I-880 Union	48	46% (22)	71% (34)	88% (42)
ALL LOCATIONS	144	38% (55)	51% (73)	60% (87)

Comparison of Infotek data and manual counts

A comparison of Infotek data with manual counts of trucks and total volumes were in general agreement, with the total volumes matching more closely. **Table 13** summarizes the difference between Infotek truck volumes and total volumes compared to the manual counts for each location.

Table 13: Comparison of Infotek and manual counts of total vehicles

Deployment Location	Evaluation Date, Time period	Percent difference
I-80 Ashby Avenue WB	11/1, 3:45-4:30	0.97%
I-880 Union NB	11/1,11:45-12:45	2.65%

District 7 locations

Comparison of Infotek data and Caltrans TMC data

The long vehicle count results of the Infotek data generally matched the Caltrans data for the deployment locations for daily results. As shown in **Table 14**, the average daily difference between the Infotek long vehicle counts for all locations was 12.11% (ranging from 6.68% and 16.31%). The State Route 101 location had the best performance with an average daily difference of 9.60% (ranging from 6.68% to 14.42%). **Table 15** examines the differences between Infotek data and Caltrans data at the hourly level and summarizes the number of Infotek samples within 5%, 10% and 20% of Caltrans results. Including data from all locations, 25% of the Infotek data points were within +/-5% of the Caltrans data, and 72% were within +/- 20%. The best performance was at the State Route 101 location where 36% and 95% of the Infotek samples were within +/- 5% and

+/- 20%, respectively, of the Caltrans data. The differences in the daily and hourly results could be due to sample time synchronization factors.

Table 14: Daily percentage differences between Infotek and Caltrans

Deployment Location	Range of daily percentage differences	Average daily difference
US-101 Downtown	6.68% to 14.42%	9.60%
SR-118 Simi Valley	14.87% to 16.31%	15.73%
I-210 Claremont	10.31% to 12.29%	11.00%
ALL LOCATIONS	6.68% to 16.31%	12.11%

Table 15: Infotek deviation from Caltrans (hourly samples)

Deployment Location	Total samples	Samples +/- 5% (samples)	Samples +/- 10% (samples)	Samples +/- 20% (samples)
US-101 Downtown	72	36% (26)	84% (61)	95% (68)
SR-118 Simi Valley	72	13% (9)	35% (25)	51% (37)
I-210 Claremont	72	26% (19)	47% (34)	71% (51)
ALL LOCATIONS	216	25% (54)	56% (120)	72% (156)

Comparison of Infotek data and manual counts

A comparison of Infotek data to manual counts of trucks and total volumes were in general agreement, with the total volumes matching more closely. **Table 16** and **Table 17** summarize the difference between Infotek truck volumes and total volumes compared to the manual counts for each location.

Table 16: Comparison of Infotek and manual counts of long vehicles

Deployment Location	Evaluation Date, Time period	Percent difference
US-101 Downtown NB	5/17,11:15-12:15	7.73%
US-101 Downtown SB	5/17,11:15-12:15	15.94%
SR-118 Simi Valley	5/17, 3:45-4:30	12.33%
I-210 Claremont	5/18, 3:45-4:30	6.06%
	Average difference	10.5%

Table 17: Comparison of Infotek and manual counts of total vehicles

Deployment Location	Evaluation Date, Time period	Percent difference
US-101 Downtown NB	5/17,11:30-11:45	0.28%
US-101 Downtown SB	5/17,11:30-11:45	0.89%
SR-118 Simi Valley	5/17, 4:00-4:15	-1.71%
I-210 Claremont	5/18, 4:00-4:15	6.16%
	Average difference	2.26%

Summary

The Infotek Wizard ILDA provides total volume, speed, occupancy and long vehicle count data for dual-loop and single-loop configurations of freeway detector stations. In comparing the Infotek results to the reference data (PeMS or Caltrans District 7 TMC), the data can vary substantially on an hourly level, but these differences appear to average out so that the daily results are in general agreement. The differences appear to be influenced by deployment location, rather than by time of day or traffic-volume relationships. These differences may indicate the need for additional fine-turning at these locations. In some cases, the data also shows smaller variance for the middle lanes and greater variance for the outer lanes; this may indicate that speed (or the variety in the sample speeds) may be a factor in either the Infotek or reference data.

A limited comparison of Infotek total volume and long vehicle count data with manual counts showed close agreement between the two for total volume, but greater differences for the long vehicle count. This could indicate that additional fine-tuning could increase performance.

Discussion with Caltrans staff indicated significant interest in some of the other features of the device that were not explicitly included in this evaluation. These features can be accessed through the cellular network, reducing travel time by maintenance and engineering staff to the monitoring stations. These features include the following:

- *Loop diagnostic tools* – These allow the user to check whether loops are working and if they are configured in the correct order (dual loop configuration).
- *Controller interface* – The Wizard has a serial interface that could be connected to the 170/2070 controller for remote access.
- *Remote Cabinet reset* – The Wizard can be set-up and wired to allow Caltrans staff to reset the cabinet from the office rather than physically going out to the field.

7. Recommendation to Caltrans

PROS	CONS
Total daily volume data closely matches manual counts.	Requires field calibration of Caltrans detector cards at each deployment location.
Can provide vehicle classification (length data) from single-loop and dual-loop detector configurations.	Accuracy of results may vary based on variance in volume or speed.
Provides cellular communications link to field controllers. Useful for items like cabinet and detector rack remote reset.	Recurring cellular communications costs[5].
Includes loop diagnostic tools	
May be less expensive than 170/2070 controller	
Device is programmable and format of data can be easily changed based on user needs.	

[5] Typical Caltrans dial-up and leased-line communications methods also have recurring costs.

Appendix A
Vendor Specification Sheet

cingular
raising the bar
Authorized Dealer

InfoTek Wizard™

The Next Generation Wireless Modem

TRANSPORTATION
- Intelligent Loop Detection
- SCADA
- Amber Alerts

UTILITIES
- SCADA
- Automatic Meter Reading

RETAIL
- Point of Sale (POS)
- ATM Banking
- Vending Machines

SECURITY
- Intrusion Detection
- Border Protection
- Autonomous Operation

HEALTH CARE
- Remote Patient Care
- Telemedicine/Telehealth

OVERVIEW

The InfoTek Wizard is a unique, GSM based GPRS/EDGE modem certified by Cingular Wireless. This next generation, versatile and easy to use intelligent modem is Java™ programmable with 32 digital inputs and 8 digital outputs. The Wizard also operates as an external wireless modem with serial connectivity which offers a cost effective alternative to dial-up and leased lines. The Wizard is an ideal solution for telemetry, SCADA, and remote sensory devices.

The embedded Java™ runtime environment executes custom applications locally, thus reducing network bandwidth usage and latency. The Java development environment allows access to TCP/IP and UDP/IP network protocols, interface to GPS receivers, SMS text messaging, SMS command/alarm relay, and digital IO monitoring.

The Wizard provides the platform for potential applications ranging from transportation, utilities, retail, security, and healthcare. The Cingular GSM Network with its flexible data rate plans reduces recurring cost, with ease of deployment. The GSM Network allows users to stay connected without any airtime charges until real data is transferred.

Affordability, scalability and seamless integration makes the InfoTek Wizard one of the most dependable and cost-effective choices in the wireless M2M market today.

Intelligent GSM Wireless Computing Platform

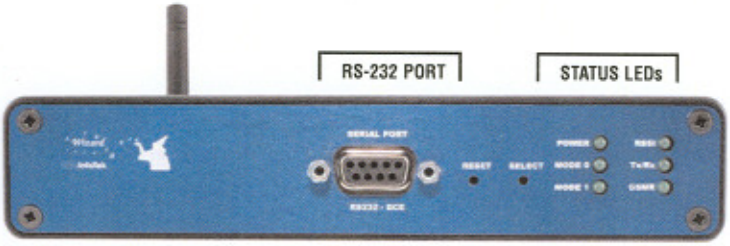


Figure 1. Wizard Front: Shows both RS-232 Ports and Status LEDs. Modem measures 6" x 6" x 1".

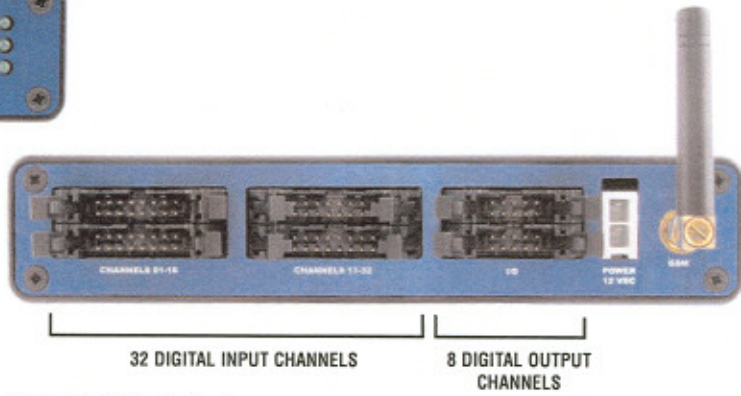


Figure 2. Wizard Back

Java programming

Improved data capacity through EDGE

Incorporated TCP/IP and UDP/IP stacks

Seamless integration for standard NMEA GPS modules

Remote I/O control via SMS

WIRELESS COMMUNICATION

- Network: 1900/850 MHz GPRS/EDGE
- Edge multislot class 2 (2+1) and mobile station class B
- GPRS multislot class 6 (2+1) and mobile station class B
- HSCSD multislot class 2 (Not supported in 850/1900 MHz)
- SMS

INTEGRATED JAVA PROGRAMMING

- 1MB persistent memory
- 128KB Java™ program memory
- 256KB dynamic RAM size
- J2ME

SERIAL INTERFACE

- RS-232 DB-9m
- Throughput up to 115 Kbps
- Full signal support for TX, RX, RTS, CTS, DSR, and DCD

- TCP/IP and UDP protocol
- Over-the-air application downloading
- HTTP and CORBA client and server
- Real Time Clock (RTC)—time query from GSM network
- GPS support
- Remote I/O Controls via SMS

INTERFACES

- 32 digital inputs
- Sampling rates: 2 ms, 5 ms, 10 ms, and 20 ms
- 8 digital outputs
- 3 analog inputs/outputs
- 1 RS 232 serial port

OPERATING CONDITIONS

- -25° C to +55° C (-13° F to +131° F)
- Relative humidity: 5% to 95% (noncondensing)

STATUS LEDs

- Power On
- Tx/Rx
- GSMR network registration
- RSSI signal strength

POWER REQUIREMENTS

- Digital I/O voltage level 1.8–5.0V user adjustable
- 12VDC power supply

STANDARD AT COMMAND SUPPORT

- Windows dialup networking (PPP)

InfoTek

333 Hegenberger Road, Suite 388
Oakland, CA 94621

Phone: (510) 383-9990
Fax: (510) 383-9770

info@infotekcom.com
www.infotekcom.com

InfoTek ILDA™

Intelligent Loop Detection Application

Polls loop detector cards at 100 times per second

Captures volume, speed, loop occupancy, and vehicle length

MS Access, Oracle, or MS SQL database compatible

Automatic downloading

Wireless GSM Modem

cingular raising the bar
Authorized Dealer

OVERVIEW

ILDA is an Intelligent Loop Detection Application that provides volume, speed, loop occupancy and length classification by polling the output of any inductive loop detector card at 100 times per second . ILDA runs on the InfoTek Wizard™, a Java™ programmable wireless GPRS/EDGE class intelligent modem.

LOOP DATA

- Summarizes volume, speed, occupancy, and vehicle length counts into typical 15-minute bins (Dual Loop Configuration)
- Vehicle length bins 0-20 feet, 20-40 feet, 40-60 feet, 60 or more feet. Length classifications are reprogrammable. (Dual Loop Configuration)
- Summarizes volume, occupancy, and long-vehicle counts into typical 15-minute bins. (Single Loop Configuration)
- Supports up to 28 loops or 14 speed traps
- Can poll or broadcast volume, speed, and occupancy to traffic management centers as frequently as required or every 30 seconds
- InfoTek Data Collector Software automatically collects data from ILDA. No manual downloading required

SYSTEM ARCHITECTURE

ILDA works with up to 28 loops in dual or single loop configurations. ILDA makes use of InfoTek Data Collector™ for traffic data collection, management and traffic alert notification. The Java based InfoTek Data Collector™ Software automatically collects accurate traffic data from the field and stores it into MS Access, Oracle or MS SQL databases. The ILDA Report generator provides customized reporting.

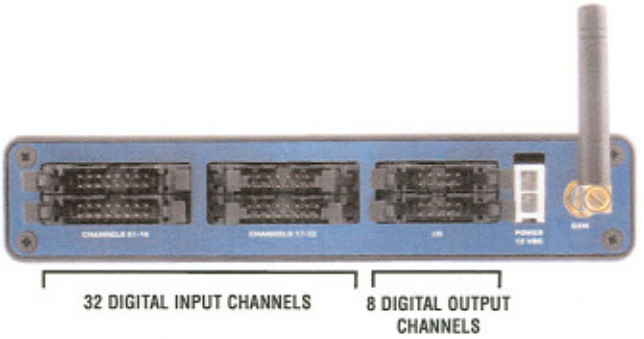
DUAL LOOP CONFIGURATION

In dual loop configuration, ILDA polls both the lead and trail loops in real-time and provides accurate volume, speed, occupancy, and vehicle length counts. Reporting intervals are user definable.

SINGLE LOOP CONFIGURATION

In a single loop configuration, ILDA polls a single loop in real-time and provides accurate volume, occupancy plus estimated speed and long-vehicle counts.

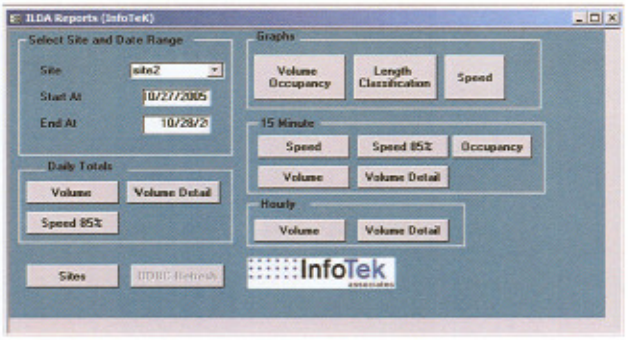
Intelligent Loop Detection Application



ALARMS & INTELLIGENT LOOP DETECTION

Custom alarms can be developed using Java to provide real-time alert notification when ILDA detects special traffic conditions. Some examples include:

- Alert the traffic management centers when traffic suddenly slows down
- Alert the traffic management centers of changing traffic conditions and pre-defined thresholds
- Real-time SMS or email alarms to multi destinations
- Warn a large truck that it is speeding on a dangerous road by flashing on a CMS sign through the I/O pins and a relay
- Alert the traffic management centers when traffic suddenly slows down



INFOTEK DATA COLLECTOR™ SOFTWARE

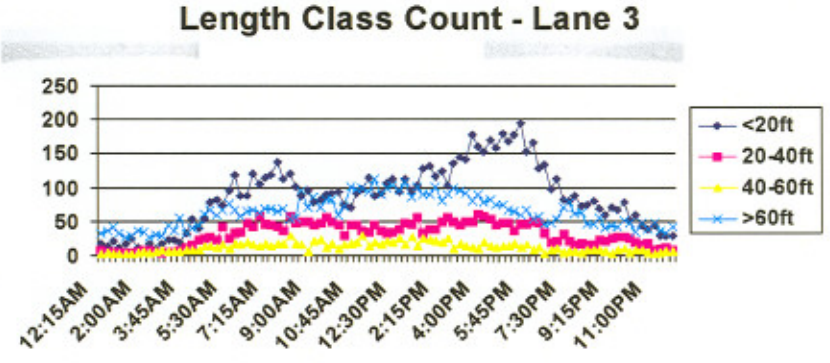
The Java based InfoTek Data Collector™ Software automatically collects traffic data from any field device over the wireless GSM network and stores it in a database. Collects data from ILDA and other field sensory devices.

- Stores 15-minute interval data into relational database
- Oracle, MS Access and MS SQL compatible
- TCP/IP and UDP/IP communication protocols
- Integrates real-time data into ATMS, live maps, and web-based applications
- Can be customized to work with existing TMC polling systems
- Customized alarms and notification

CABLING AND ANTENNA

ILDA's standard detector output cables are equipped with diodes to allow coexistence with 170/2070/NEMA and other controllers with no interference

- Easy installation and integration with existing controllers and loop detectors
- Cable connects InfoTek Wizard directly to loop detector outputs
- GSM antenna mounts on top of traffic cabinets for wireless connectivity



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ITS Pilot Project Demonstration

NAVTEQ 511 Level Two Evaluation

Prepared For
Caltrans

July 2006
FINAL

Prepared By
Kimley-Horn and Associates

ITS Pilot Project Evaluation

NAVTEQ 511 Level Two

Vendor Contact Information:

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http://www.NAVTEQ.com

Evaluation Summary

Vendor/Project – NAVTEQ/511 Level Two Demonstration

The 511 Level Two system provides personalized services to enhance the existing Bay Area 511 system. This technology was developed by NAVTEQ utilizing the company's digital map coverage. NAVTEQ planned to include the following elements in the 511 Level Two system demonstration:

- **Door-to-door driving directions** for the entire Bay Area
- **Ability to specify address or select point of interest (POI)** as origin and destination
- **Real-time parking garage space availability**
- **Ability to make parking space reservations**
- **Voice recognition interface** to remain consistent with the existing Bay Area 511 system.
- **Customized Personal Identification Number (PIN) capability** which allows user to "store" directions and access them at another time from the same phone

During the 2005 ITS World Congress, NAVTEQ's My511 project was showcased in the Bay Area. All the above elements except the real-time parking availability and parking reservation were actively deployed during that period.

Delivery: Does demonstration satisfy Vendor's stated objectives for Caltrans?

Easily navigable user interface compatible with existing 511 voice system

☒ YES ☐ NO
☐ NOT VERIFIED

This function performed accurately during the evaluation.

Accurate and practical PIN function

☒ YES ☐ NO
☐ NOT VERIFIED

This function performed accurately during the evaluation.

Accurate and clear directions between locations and POIs

☐ YES ☒ NO
☐ NOT VERIFIED

Although the data was generally correct, testers encountered some segment lengths, cardinal directions, and streets which were incorrect. It is recognized that many of the limitations observed in the demonstration might be addressed with further testing and full deployment.

Varied choice set for POIs reflecting typical Bay Area user needs ☒ YES ☐ NO ☐ NOT VERIFIED

See report for additional observations.

Accurate parking availability data ☐ YES ☐ NO ☒ NOT VERIFIED

The real-time parking space availability function did not appear to be available during the evaluation period.

Practical and reliable parking reservation system ☐ YES ☐ NO ☒ NOT VERIFIED

The real-time parking space availability function did not appear to be available during the evaluation period.

Test customer willingness to pay for 511 Level Two services ☐ YES ☐ NO ☒ NOT VERIFIED

NAVTEQ did not supply relevant information on this item for evaluation.

Key Observations

This project was initially deployed as part of the ITS World Congress, and reportedly turned off shortly after the conference (without notice). The shutdown was discovered in March 2006. Repeated attempts to contact NAVTEQ by telephone and email were made between March 2006 and May 2006 in order to obtain additional information regarding the NAVTEQ 511 Level Two deployment and status. None of these queries were answered. This evaluation is based on the available information and observations prior to March 2006.

Operator cost

- *NAVTEQ did not furnish information on the operator's initial cost to implement and on-going maintenance costs.*

User cost:

- Currently, it is assumed that users will be able to access the 511 Level Two system free of charge from any landline telephone or cellular phone. In the future, this higher -level service may be available for a fee. *NAVTEQ did not furnish information regarding user surveys of level of satisfaction and willingness to pay for these kinds of services.*

Integration with existing Bay Area 511:

- During its operation, the service could be accessed by calling 511 from any Bay Area telephone and entering a special menu.
- The system could be made significantly more beneficial to the user if it included 511 real-time traffic information and travel time estimates in its route guidance.

Overall data accuracy and functionality:

- *Door-to-door driving directions* - For the most part, the accuracy of directions provided by the service was acceptable. However, some errors were detected. For example, the minimum distance to travel on each route segment given by My511 instruction is ¼ mile which can lead to missed turns if the actual needed traveling distance on that route segment is less than ¼ mile. Also, the cardinal highway direction given by the 511 Level Two system was occasionally incorrect so the driver may be led in the wrong direction. It is recognized that many of the limitations observed in the demonstration would likely be addressed with further testing and full deployment.
- *Ability to store trip directions using a PIN for future access* – This function worked satisfactorily. A user can construct a trip and call back at a later time from the same phone to have the option to access the last trip direction. In addition, a reference number is assigned to each segment of the trip and the user has the ability to obtain the direction starting from any point along the trip using the reference number.

User acceptance:

- *User's ability to navigate through the 511 Level Two system* – For known POI and addresses, it is easy to navigate through the system. Otherwise the user will need to navigate through POI menus as described in the following section.
- *Possible delay caused by an abundance of POI choices* – If a POI is not known, process could be more lengthy. Lengthy sub-menus categorize various POI which is tedious for the user.
- *Accuracy of voice recognition* – The system appeared to work well with the desired functionality.
- *Accuracy of directions provided*—See discussion above.

Recommendation to Caltrans

PROS	CONS
▪ Covers route information for entire country ▪ Directions provided similar to those available through commercial websites such as maps.yahoo.com and mapquest.com ▪ Saves last direction request and allows access to the same direction ▪ Numerous points of interest ▪ Low disconnection rate	▪ Difficult to interpret and utilize some of the directions provided due to occasionally inaccurate traveling distance and cardinal directions ▪ Sometimes difficult to communicate with computerized voice system ▪ Menu navigation could use improvement so that the users would not spend long time to locate the information they need ▪ Accepts non-existent addresses ▪ Does not yet incorporate real-time traffic data in traveling directions, while main 511 system has real-time data capability ▪ Smallest increment of ¼ mile can misguide user

Evaluation Details

1. Delivery

Vendor's Stated Objective in Caltrans contract:

- ❒ Test customer interest in Level Two services, including at a minimum parking and traffic-enabled door-to-door routing
- ❒ Leverage additional map content developed for several applications in other World Congress projects
- ❒ Highlight voice data

2. Project Specifics

Deployment Date(s) and Time(s)	Evaluation Date(s) and Time(s) Include weather conditions
November and December 2005 (Deployed as part of ITS World Congress and turned off shortly afterwards. The exact deployment date range was not provided by NAVTEQ)	November 6-10, 2005 February 1-3. 2006
Deployment Location(s) Include diagram or map if applicable	**Evaluation Location(s) Include diagram or map if applicable**
NAVTEQ claims that addresses and POIs are available for all of United States. (This demonstration focused on the San Francisco Bay Area.)	Within San Francisco Bay Area; plus nationwide origins and destinations

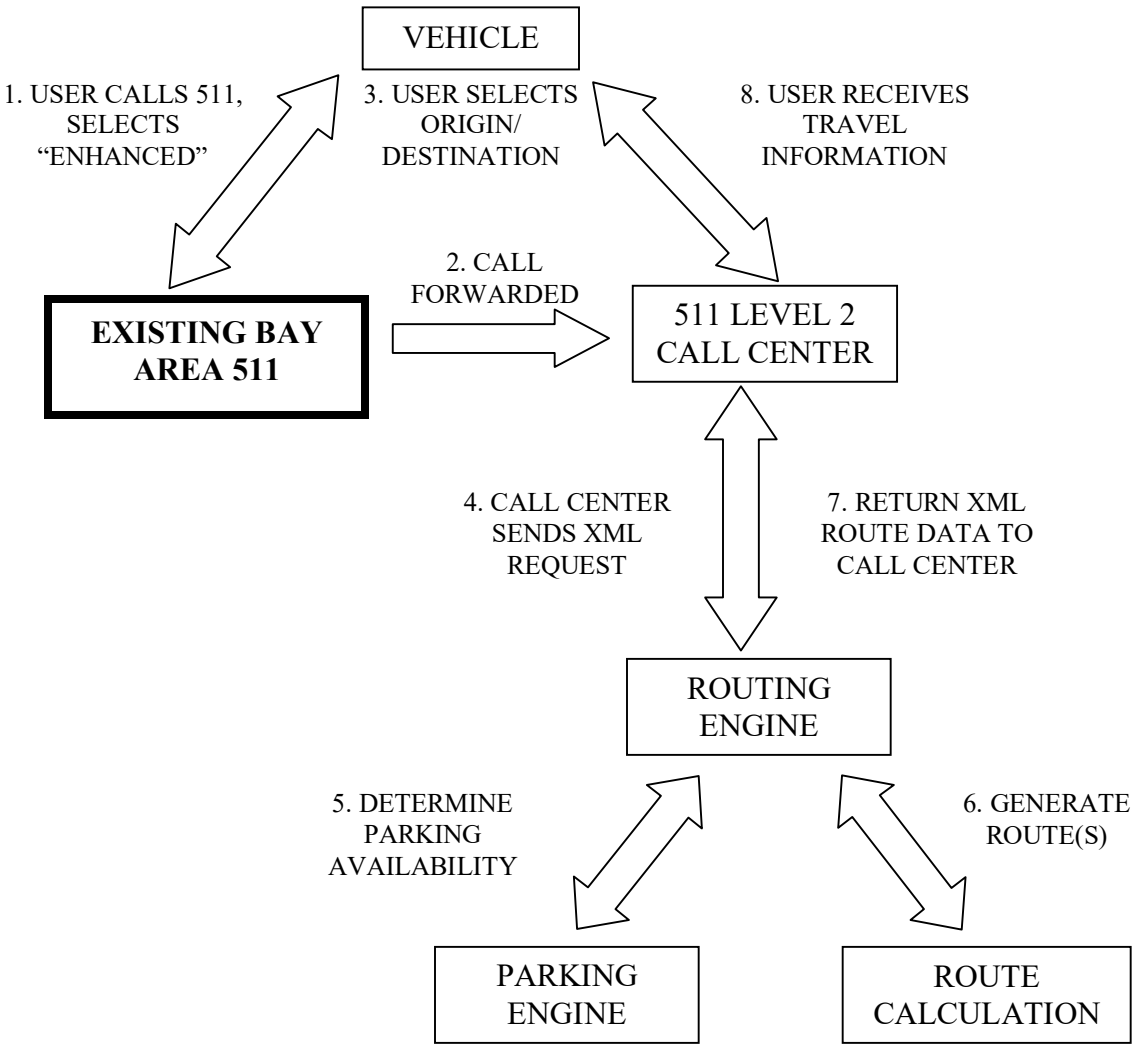
The project was initially deployed as part of the ITS World Congress, and reportedly turned off shortly after the conference (without notice). The shutdown was discovered in March 2006. Repeated attempts to contact NAVTEQ by telephone and email were made between March 2006 and May 2006 in order to obtain additional information regarding the NAVTEQ 511 Level Two deployment and status. None of these queries were answered. This evaluation is based on the available information and observations prior to March 2006.

3. Technology

3.1 Technology or System Description

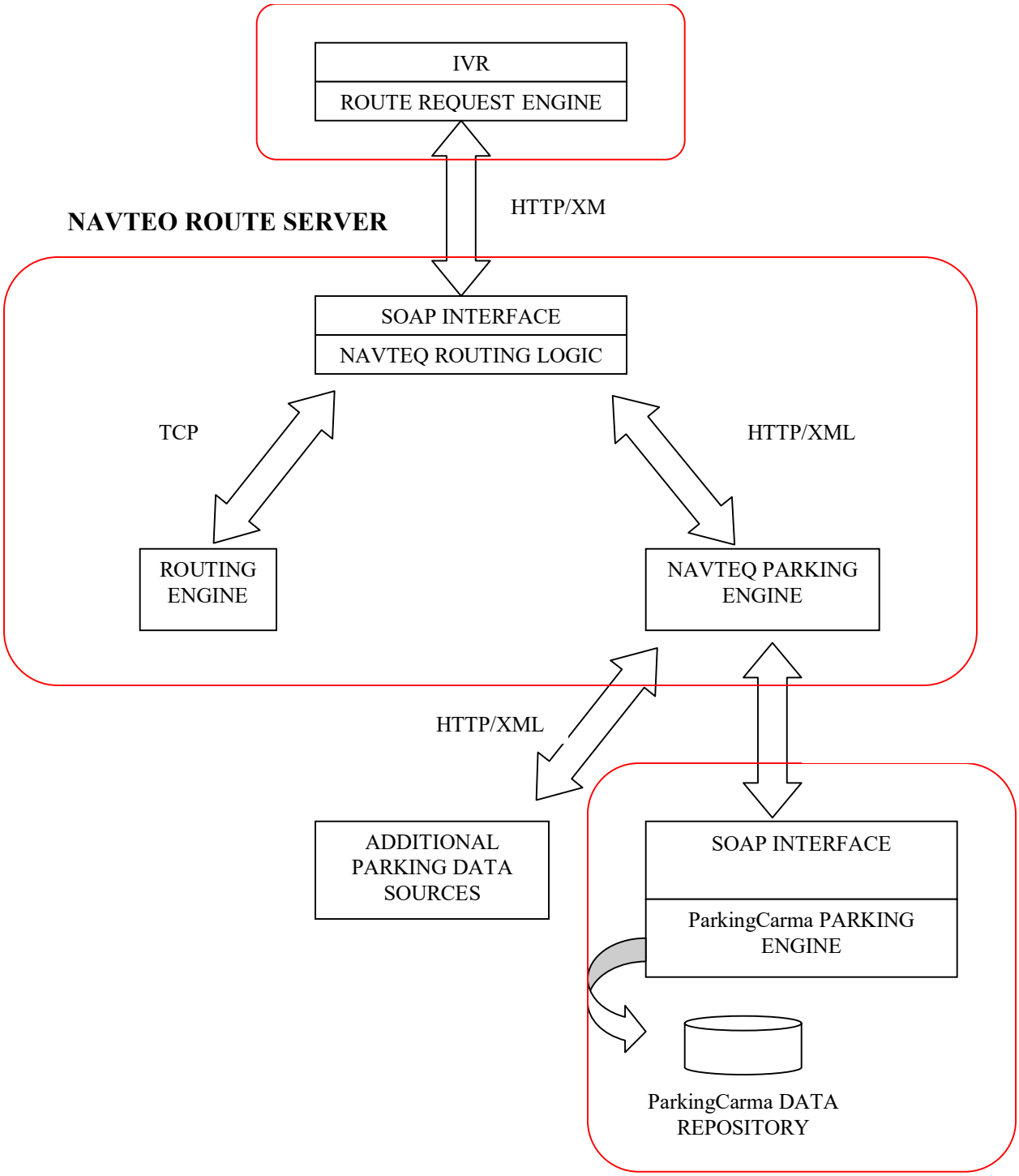
The NAVTEQ 511 Level Two is a separate service that can be accessed through the San Francisco Bay Area 511 telephone service. Through 511 Level Two, the user can access enhanced services, including door-to-door instructions and parking availability/ reservations. The interaction between these various systems is indicated in the two diagrams below.

511 Level Two Architecture
(Source: NAVTEQ)



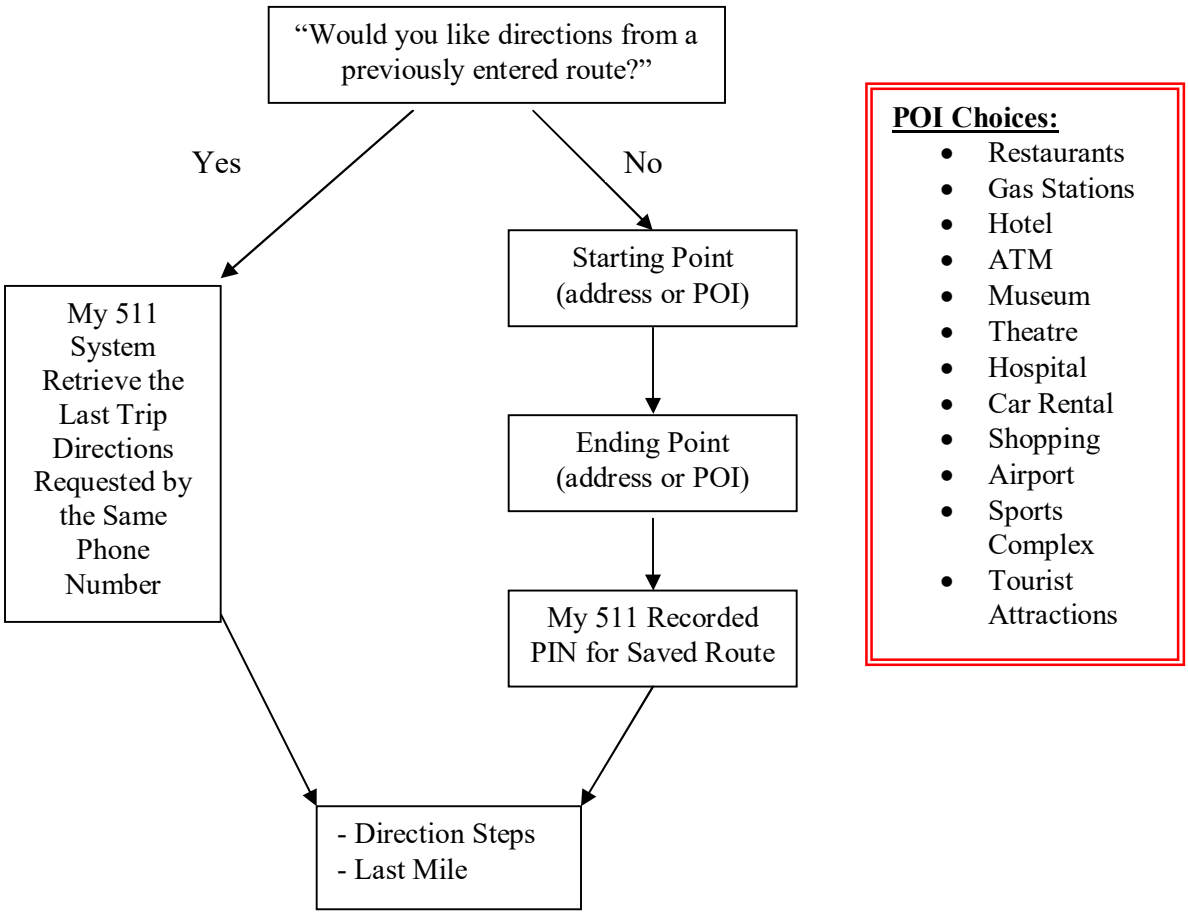
511 Level Two Components

(Source: NAVTEQ)



Additional documentation on the system (e.g. specifications, schematics and diagnostics) may be available, but was not provided by NAVTEQ for this evaluation.

After accessing the 511 Level Two call center, the phone menu tree accessed by users is illustrated below.



POI = Point of Interest
PIN = Personal Identification Number (currently assigned based on cell phone number)

3.2 Previous Evaluations (including vendor's own) and/or Similar Technology Deployments

There have been no previous evaluations conducted on this technology.

3.3 Cost

NAVTEQ did not furnish information on the operator's initial cost to implement and on-going maintenance costs. For users, the service during the ITS World Congress was free of charge. In the future, it appears that a higher level service would be available for a fee. *NAVTEQ did not furnish information regarding user surveys of level of satisfaction and willingness to pay for these kinds of services.*

4. Performance Measures

Performance measures are defined here for this project and are divided into different categories for evaluation and discussion: Quantitative, Qualitative, and Other Performance Factors.

Definition of Performance Measures

What does the technology or system measure?

The system provides accurate, reliable driving directions in response to user queries.

Accuracy of Outputs

What level of accuracy is considered successful for each of the above measures? Did this project satisfy those accuracy levels? ☐ YES ☐ NO

This evaluation currently relies on a limited set of observations. The availability of additional data from NAVTEQ would be needed to determine the "successful" level of accuracy.

4.1 Quantitative Outputs

Accuracy

1. Did the system provide accurate and clear directions between locations and POIs?

After performing numerous experimental trials using the step-by-step driving directions, it appears that the distances are rounded to the nearest quarter mile, which may introduce inaccuracy issues. Downtown areas with closely spaced intersections can experience a higher level of inaccuracy.

Reliability

1. How reliable was the PIN function in recognizing previous callers?

No issues were experienced with the PIN function during evaluation of the service. It successfully recalled previously entered directions on several occasions.

2. What steps are taken to ensure security of the system and privacy?

The PIN function can identify each unique phone number. There are no additional security measures to prevent one person from accessing another's directions using the same phone.

4.2 Qualitative Outputs

Reliability

1. Were there any technical difficulties experienced which led to disconnection from the 511 Level Two system?

No users reported any disconnections during the evaluation period observations and trials. However, the system would frequently return the user back to the main menu when it couldn't understand an address, POI entry or menu selection. On occasion, the system placed the user on indefinite hold at the menu

Productivity

1. Did the system included a varied choice set for POIs reflecting typical Bay Area user needs?

POI choice set was comprehensive

2. Was the Interactive Voice Response (IVR) User Interface easy to use and understand?

IVR user interface was easy to follow. Voice recognition problems were experienced.

3. Were directions provided clear and easy to understand?

It was observed that the step-by-step driving directions provided cardinal directions. Often times roadway users may not be aware of their cardinal orientation. Furthermore, if the suggested turning maneuvers were solely provided, without the cardinal direction, it would eliminate the need to provide directions from intersection to intersection. Reducing the number of steps and simplifying the system would create a more user friendly environment and reduce overall delay.

4. How satisfied were customers with their overall experience?

NAVTEQ did not furnish information on user surveys of subjective reactions and comments regarding usefulness, practicality, reliability.

5. Did users change behavior based on project?

NAVTEQ did not furnish information on user surveys of subjective reactions and comments.

6. How do these performance measures relate to Caltrans' 9 Performance Measures?

Caltrans' performance measures are used to assess the operations of multi-modal transportation systems in order to create a more accountable framework for decision making. The following table relates the project performance measures against the Caltrans performance measures.

	Caltrans Nine Performance Measures								
	Mobility/Accessibility/ Reliability	Productivity	System Preservation	Safety	Environmental Quality	Coordinated Transportation and Land Use	Economic Development	Return on Investment	Equity
Outputs Measured									
Accuracy	✓	✓			✓				
Cost	✓	✓						✓	
Reliability	✓	✓							
Productivity	✓	✓						✓	

5. Evaluation Methodology

How were the performance measures described above evaluated?

These performance measures were evaluated using the following methods:

A sampling of eight Bay Area and four non Bay-Area routes were selected as part of the evaluation. These samples varied to include POI destinations and street addresses and other factors as described below:

- **Short distance driving directions and corresponding distances**
- **Long distance driving directions and corresponding distances**
- **Differing vicinities such as**
  - **Metropolitan/Downtown**
  - **Rural/Urban**

For the driving directions feature, the accuracy of the suggested turning maneuvers as well as its associated distances are essential elements in providing the user proper geographic guidance. This accuracy was assessed in each sample by comparing the 511 Level Two driving directions with directions output from other reliable sources (for example, KHA familiarity with the vicinity, or other online mapping services).

Testers commented on any system failures (for example, hang-ups or other system down time) to quantify system reliability.

The evaluation methodology also included obtaining the following information from NAVTEQ (as available) :

- **Usage statistics, including average daily usage, average service time/ length of call, most popular service, destinations, etc.**
- **Results of customer feedback surveys.**
- **Information on information impact customer choices.**
- **Other information as determined to be relevant during the sampling evaluation above.**

6. Evaluation Results

The following results were obtained during the evaluation and sampling of the 511 Level Two system conducted during the first week in February 2006.

Accuracy

The system was generally accurate in the directions it provided but several issues arose that would prevent the user from successfully utilizing the 511 Level Two directions to navigate to their destination. Directions in many cases were similar to those provided by Google Local or Mapquest. Driving distances and times in most cases were similar as well to those provided by online navigation services. Accuracy issues with the service include:

- Starting locations
  - The starting locations in some cases are incorrect. For example, the starting location for the Oakland Airport was reported by 511 Level Two on Golf Links Rd.

- Minimum driving distance
  - All distances are rounded to the nearest quarter mile. This could potentially cause the user to miss the appropriate turning location if it were less than this (e.g. between intersections and ramps).

- Missed merging and diverging locations
  - Locations where freeways and roadways diverge are not listed in the driving directions. For example, driving from Oakland to Los Angeles, no

instruction is given for the driver to transition from SR-238 to I-580 to I-5. Instead, the user is told to take SR-238 to I-210, which is located several hundred miles away from SR-238.

- Cardinal directions do not agree with appropriate turning movements
  - The cardinal direction is given, which if the user does not know their precise heading does not provide any value to the user. Furthermore, freeway directions are given in the cardinal direction, not the stated direction of the freeway. For example, in leaving downtown Oakland, the user is told to take I-880 southeast and SR-238 southeast. These highways are north/south freeways and directions should be provided relative to the signage posted for those highways, not the cardinal direction. Additionally, the use of cardinal directions for freeway ramps merely confuses the user since the freeway ramp direction may be completely opposite of the desired freeway direction. For example, the ramp direction could be stated as northeast even though the user may need to go south on the provided freeway.

- Incorrect/Inefficient directions
  - In most cases the directions were the most direct and efficient, but there were errors. For example, to arrive at Union Square in San Francisco, the user was directed to drive north on 3rd St past the destination.

- Accepts non-existent addresses
  - While the system won't allow a street that doesn't exist to be entered, it will accept any address number. For example, all addresses on College Avenue in Berkeley, CA, number in the 2000s, but the system will accept and provide directions for any street number, such as 5 College Avenue. This could lead the user to obtain directions to the wrong point while believing they have the correct address.

- Driving times not based on real-time traffic data
  - While 511 Bay Area provides real-time traffic and incident data between a number of points, 511 Level Two does not. For example, it provided a driving time of 16 minutes between Emeryville and Union Square. A check of 511 at that time suggested a driving time of at least 28 minutes. The incorporation of real-time traffic data could lead to the suggestion of quicker routes and provide the user a better indicator of their actual driving time.

The issues mentioned above all occurred during the eight trials conducted using Bay Area origins and/or destinations. Since the system provided the ability to obtain directions to/from any address or POI located throughout the country, additional trials were performed to further test the functionality and accuracy of the system. The following list errors noticed exclusively in the non-Bay Area trials:

- Cardinal directions do not agree with appropriate turning movements
  - For example, leaving John Wayne Airport in Orange County, the user is told to take I-405 east, even though I-405 is a north/south freeway.

- Incorrect/Inefficient directions
  - For example, leaving John Wayne Airport, the user was directed to take streets parallel to the freeway for approximately a mile instead of entering the freeway directly outside of the airport.
- Directions to/from incorrect origin/destination
  - While in most cases the stated origin/destination is utilized in the directions, this is not always the case. When the system attempted to give directions to 511 Fourth Avenue in San Diego it stated the correct address but guided the user to an address on Via Banco, several miles away.

- The parking reservations system feature could not be accessed during the evaluation.

Practicality and ease of usage

The system can be reached from anywhere in the Bay Area and can provide nationwide directions, indicating great potential. The user can obtain previously requested directions from any phone allowing them to obtain directions while in the process of driving the requested route. Nearby parking lots were provided for many addresses and POIs. In some cases these lots were within a couple of blocks, in others they were well beyond a reasonable walking distance, leading to the conclusion that more parking facilities need to be added to the database. There was no ability provided to obtain a parking reservation at these facilities.

A major concern is the poor user operation interface. While the actual menu structure is simple and easy to understand, maneuvering through the menu and achieving the desired route information is quite tedious. The following points highlight the difficulties that arise in use of the system:

- Difficulties with voice recognition software
  - Frequently “no” responses were interpreted as “yes”, especially when asked if directions should be repeated or if the user is seeking an already entered route.

  - City names were often not understood or incorrectly understood. If the wrong name was interpreted it was difficult to go back and correct. For example, Berkeley was at times interpreted as King's City.
  - Names of POIs were very restrictive. For example, for the Courtyard hotel, one couldn't say Courtyard by Marriott, even though that is the widely used name.

- Difficulties understanding computerized voice
  - It is extremely difficult to understand POI names when they are being listed. For a listing of tourist attractions in San Francisco, CA, more than half of the names were not discernable.

- Difficulties with interpretation of directions
  - The use of cardinal directions significantly lengthens the time it takes to go through the route direction steps, while not providing significant benefit to the user and often incorrect.
- POI Use
  - The number of POI in the system should be increased. One test was to find directions to Memorial Stadium at UC Berkeley. It was not listed as a sports complex and the tester was unable to even locate UC Berkeley as a POI.
  - The list of choices for hotels in Berkeley, CA, brought up hotels in San Ramon, Dublin, Pleasanton, Castro Valley, Livermore and Hayward, but none in Berkeley. But when a specific Berkeley hotel was searched for, it was found.
  - When a franchise POI, such as a gas station or hotel was selected, the user must go one-by-one through the entire list of that POI in the given city. For gas stations, this required going through numerous listings, saying "no" to each one before the desired one was reached. There was no apparent way to select a specific franchise POI without going through the entire list.

- Menu operations
  - The system would frequently return the user back to the main menu when it couldn't understand an address, POI entry or menu selection. This erases all of the information already provided by the user.
  - Attempting to correct a voice recognition mistake was difficult and time consuming.
  - On occasion, the system places the user on indefinite hold.

NAVTEQ did not furnish information on user surveys of subjective reactions and comments.

Other Observations

When the information was correct, the 511 Level Two system generally provided quality directions between two points with reasonably accurate driving distance and time estimates, when compared with other direction services such as Mapquest or Google Local. However, knowledge of the particular area is almost essential to detect any errors. There are numerous POI in the system that work seamlessly for all entries throughout the United States. In addition, the last route inquiry is stored for each phone number.

The main difficulty arises in the use of the system, primarily with the voice recognition software and computerized responses. It frequently does not understand or incorrectly interprets the user's menu and location requests. Difficult menu operations can cause additional frustration for the user.

It is recognized that many of the limitations observed in the demonstration might be addressed with further testing and full deployment.

7. Recommendation to Caltrans

PROS	CONS
▪ Covers route information for entire country ▪ Directions provided similar to those available through commercial websites such as maps.yahoo.com and mapquest.com ▪ Saves last direction request and allows access to the same direction ▪ Numerous points of interest ▪ Low disconnection rate	▪ Difficult to interpret and utilize some of the directions provided due to occasionally inaccurate traveling distance and cardinal directions ▪ Sometimes difficult to communicate with computerized voice system ▪ Menu navigation could use improvement so that the users would not spend long time to locate the information they need ▪ Accepts non-existent addresses ▪ Does not yet incorporate real-time traffic data in traveling directions, while main 511 system has real-time data capability ▪ Smallest increment of ¼ mile can misguide user

In

ITS Pilot Project Demonstration

Probe vehicle technology (Outreach and others) Evaluation

Prepared for Caltrans

October 2006 FINAL

Prepared By Kimley-Horn and Associates

ITS Pilot Project Evaluation

Probe Vehicle Technology

P:\097317000 - Caltrans Pilot Project Demonstration - RRD\VendorDemonstrations\Outreach - AD\EVALUATION - Outreach -FINAL.DOC

Evaluation Summary

Vendor/Project – Probe Vehicle Technology (Outreach and others)

Accurate and sufficient traffic data collection is the foundation of almost every service in the ITS industry. Transportation agencies have long been relying on highway surveillance devices, such as inductive loops and radar ("point-based data"), to collect traffic data. Due to the high cost and difficulty of installation, these traffic surveillance devices only cover a very small amount of the freeway network and almost none of the arterial network in the country. Recent technology advances enable vehicles to be used as probes to obtain real-time traffic data ("path-based data") that could be used to supplement or replace traditional highway surveillance stations.

This evaluation investigated the planned deployment of cellular phone-based and PDA/ GPS-based probe vehicle technologies around the country (identified by a review of technical literature). These deployments include the following locations:

- Atlanta, Georgia (cellular phone-based)
- Baltimore, Maryland (cellular phone-based, GPS-based on fleet vehicles)
- Missouri (cellular phone-based)
- Portland, Oregon (GPS-based on transit vehicles)
- San Francisco Bay Area, California (Outreach GPS-based on volunteer vehicles)

The information gathered on these deployments included interactions with Outreach staff in conjunction with the 2005 ITS World Congress in San Francisco, California, a review of technical literature and phone interviews with the agency staff of planned deployment locations.

It is important to note at this point that Outreach was the original focus of this evaluation. Unfortunately, Outreach was not able to continue the demonstration after the 2005 ITS World Congress due to a loss of financial commitment. As a result, the evaluation was directed toward the probe vehicle technology industry to review how the industry appears to be progressing. Due to the fact that probe vehicle technology is still largely an emerging technology, there is very little tangible data that is available.

1. Delivery: Does probe data appear to be a viable technology for data collection?

Based on the evaluation locations, there is uncertainty regarding the accuracy of probe vehicle data in reflecting general roadway conditions. This is primarily due to questions about whether the probe vehicle driving characteristics matches that of all drivers and whether the probe vehicle system algorithms can filter out vehicles actions not related to traffic flow conditions.

Cellular-phone-based probe vehicle systems

AirSage claimed in a test deployment in Atlanta, Georgia, that their "data is nearly always categorically correct," meaning that traffic can be categorized as moving fast, medium or slow relative to normal conditions. Future enhancements are expected to provide detailed speed information. Phone calls to GDOT were not returned and this claim could not be verified. There is no data available from the Missouri and Baltimore systems, since the project has been put on hold due to the cellular service provider opting out of the demonstration.

PDA/GPS-based probe vehicle systems

The San Francisco Bay Area, California (Outreach) system was discontinued shortly after the 2005 ITS World Congress due to research and development funding constraints so direct evaluation of the system was not possible. An evaluation of the Portland, Oregon system reported successfully determining roadway speeds based on transit-vehicle probe data in an initial test deployment. However, there have been no further tests or actual deployment of the system, and this claim could not be verified. The Baltimore system is currently under evaluation so data is not currently available.

2. Can the probe vehicle data be integrated with other data sources?

☐ *YES* ☐ *NO* ☒ *NOT VERIFIED*

Only the San Francisco Bay Area (Outreach) deployment included integration of the probe vehicle data with other data sources. Outreach claims that this was successful, but this claim could not be verified since the system was discontinued prior to this evaluation.

3. Can probe vehicle data be used to forecast roadway speeds based on real-time traffic conditions and historical data?

☐ *YES* ☐ *NO* ☒ *NOT VERIFIED*

Only the San Francisco Bay Area (Outreach) deployment included forecasting roadway speeds. Outreach forecasts were based on real-time data and four weeks of historical data. The Outreach system report includes one travel time comparison where the forecasted travel time was compared with travel time from another source, MapPoint 2004. For a road section of 20.93 miles, Outreach system forecasted the travel time to be 35.96 minutes while MapPoint 2004 gave 27 minutes without counting real-time information. From this example, it appears that the Outreach system travel time forecasts consider more than just distance. The accuracy of the calculation was not verified but could have been impacted by an incident during the real-time data collection. This feature and its accuracy could not be verified since the system was discontinued prior to this evaluation.

Key Observations

Based on the information gathered, cellular-based and PDA/GPS-based traffic probe technology seem to be a feasible technology for collecting travel time data and offers potential for an additional source of real-time traffic data for roadway agencies. However, this evaluation also uncovered several critical issues that would need to be addressed before a full-scale deployment of this technology would be successful. Other public agencies may not feel comfortable with similar deployments until these issues are addressed and would not want to risk having their project halted in the middle of deployment. These critical issues are described below:

- *Accuracy*—Based on the evaluation locations, there is uncertainty regarding the accuracy of probe vehicle data in reflecting general roadway conditions. Inaccurate data would undermine public confidence in the information, reduce the reliability of forecasted information, and make it difficult to integrate the probe vehicle data with other data sources.

- *Privacy Issues*—The idea of using technology to track vehicles could be a sensitive public relations issue for the agencies and companies involved in these deployments. Awareness of privacy issues is a necessary part of a successful deployment strategy. The public's concerns need to be addressed in a clear and well-communicated manner before and throughout the deployment.

  For the evaluated cellular-phone-based systems, the cellular service provider planned to filter all sensitive data before it is delivered to the data server. Despite these measures, the evaluated deployments were halted because the cellular service partner pulled out of the project in concern for bad publicity. The GPS/PDA-based evaluations allowed participating volunteers could choose to send the probe data anonymously or tracked non-passenger vehicles where privacy issues were less of a concern.

- *Lack of National Standard for Data format and exchange*—Despite the interest and investment in traffic probe technology, there is no national standard regarding what data can be exchanged and its format. Deployed systems rely on propriety software and negotiated agreements between one agency and one data provider. Developing such a standard could contribute to ensuring a sufficient amount of private partners.

- *Incomplete Economic Model*—These deployments are still in the early stages, so complete economic model has not yet been developed. Such a model would be useful in determining the economic feasibility of sustained deployment, including what the long-term costs to the local agency are, as well as how much of these costs might be offset by personalized subscription services to the public.

Recommendation to Caltrans

PROS	CONS
Traffic probes present the opportunity for another source of traffic data.	Algorithms for correlating probe data to roadway speeds and travel times still under development.
Less calculation required to determine travel time of an individual vehicle for a segment.	Dependent on sufficient volume of probe vehicles to produce accurate and reliable data.
Installation of equipment is less disruptive and less expensive than installation of loop detectors or other point-based vehicle detection devices.	Public will have privacy concerns about probe technologies.
Relies on existing cellular networks and/or GPS so can be deployed to cover a larger area quickly.	Privacy concerns may limit the willingness of cellular phone providers to be associated with cellular-phone-based tracking.
System could cover arterial streets network which is typically not monitored by traditional traffic monitoring technologies.	Currently, GPS-based devices are not common among drivers.
Cellular phones are common among motorists. GPS-based devices (including new cellular phones) are becoming common.	Lack of standards or protocols for data exchange increase costs for agency to switch to new probe vehicle provider.
Opportunity for private/ public partnership.	

Evaluation Details

1. Delivery

Accurate and sufficient traffic data collection is the foundation of almost every service in the ITS industry. Transportation agencies have long been relying on highway surveillance devices, such as inductive loops and radar ("point-based data"), to collect traffic data. Due to the high cost and difficulty of installation, these traffic surveillance devices only cover a very small amount of the freeway network and almost none of the arterial network in the country. Recent technology advances enable vehicles to be used as probes to obtain real-time traffic data ("path-based data") that could be used to supplement or replace traditional highway surveillance stations.

In order for probe vehicle technology to be a viable alternative to traditional point-based surveillance methods, the following objectives, in the order of necessity for implementation, need to be met:

- Ability to gather data that accurately reflect roadway conditions.
- Ability to integrate the data with other data sources, either to fill-in gaps or validate the data.
- Ability to forecast travel times and/or speeds based on real-time and historical data.

This evaluation investigated the planned deployment of cellular phone-based and PDA/ GPS-based probe vehicle technologies around the country (identified by a review of technical literature). The deployments included the following locations.

- *Atlanta, Georgia*—The Georgia Department of Transportation (GDOT) contracted with AirSage in 2005 to use cellular phone-based technology to provide traffic data in a field test on 65 miles of Interstate 75.
- *Baltimore, Maryland*—The Maryland State Highway Administration (SHA) contracted with Delcan for a two-year agreement starting in 2004 to deploy cellular phone-based and PDA/GPS-based traffic information from fleet vehicles (such as Fedex) on freeways and arterials in the Baltimore, Maryland area.
- *Missouri*—The Missouri Department of Transportation (MoDOT) contracted with Delcan in 2005 to provide a field test of cellular phone-based technology on five freeway miles and five arterial miles. The eventual plan includes statewide deployment.
- *Portland, Oregon*—The City of Portland, Oregon Department of Transportation (ODOT) and TriMet (transit service provider) initiated a project in 2003 to use TriMet buses as traffic probes using the existing GPS-based Automated Vehicle Location (AVL) equipment installed on TriMet buses. The initial phase of the project focused on collecting traffic data on arterial roadways through downtown Portland.

- *San Francisco Bay Area, California*—Outreach Paratransit (a non-profit group) initiated a project in 2005 to gather probe data from volunteer drivers (using Outreach-developed software on volunteer PDA and GPS equipment), integrate this data with speed data from other sources (including fixed roadway sensors) and to present real-time and forecasted traffic speeds on a website.

Most deployment tests regarding traffic probe technology are still focused on the ability to gather accurate data and have not gone through any deployment evaluation. Therefore, this evaluation focuses on the ability of the technology to reflect roadway conditions and does not examine the accuracy or reliability of the presentation or dissemination of data to the public.

2. Project Specifics

Deployment Locations and Dates	**Evaluation Date(s) and Time(s)** *Include weather conditions*
• Atlanta, GA: 2005 (ongoing) • Baltimore, MD: 2005 (ongoing) • Missouri: 2005 (ongoing) • Portland, OR: 2003 • San Francisco Bay Area, CA: 2005	Not specified for all locations and did not include weather conditions. When available, generally covered a time period that included weekday, weekend, peak and non-peak periods.
Deployment Location(s) *Include diagram or map if applicable*	**Evaluation Location(s)** *Include diagram or map if applicable*
Freeways and arterial corridors in metropolitan areas with heavy traffic volumes.	Evaluations generally looked at the entire deployment areas and corridors.

3. Technology

3.1 Technology or System Description

At this time, cellular phone-based and PDA/GPS-based equipment are the most common and tested technologies for tracking vehicle location. This section provides short description of each technology and the details particular for the evaluated deployment location.

Cellular-phone-based

The Atlanta, Baltimore, and Missouri deployments utilized cellular-phone-based systems. This technology functions by mining data that is already collected by cellular service providers. A cell phone's location is estimated when it leaves and enters a cell

tower's area within the cellular network. The data is transferred from the cellular provider's system to another system after all personal information is stripped and a unique ID number is assigned to each cell phone. The information is analyzed, aggregated and converted to travel time and speed estimates for roadway sections. AirSage (the Atlanta consultant) claims to have patented this technology in January 2005. It is unclear if Delcan (the Baltimore and Missouri consultant) is using the AirSage system or their own system. (Note that none of the deployment locations utilize the GPS feature required in new cellular phones by the Federal Communication Commission (FCC) to be able to locate cell phones used to make 911 calls.)

GPS/PDA-based

The Baltimore, Portland, and San Francisco Bay Area programs used GPS/PDA-based systems. This technology relies on using equipment on vehicles that collect and transmit a real-time Global Positioning System (GPS) location to a central server where the data is analyzed and aggregated. For the Baltimore deployment, the GPS/PDA devices were on-board fleet vehicles (FedEx). The deployment test in Portland used existing GPS-based Automated Vehicle Location (AVL) system on transit vehicles to estimate traffic speed. Since the driving characteristics of fleet vehicles and transit vehicles can be different than a typical passenger car, the speed data may need to be adjusted to yield effective average traffic flow data.

For the San Francisco Bay Area deployment, the GPS/PDA equipment was placed on Outreach Paratransit passenger vehicles driven by volunteers as they went about their daily routes. The PDAs (with Bluetooth GPS) are individually owned and equipped with Outreach-developed PDA probe software (written by volunteers) that determines the vehicles location and speed, and then sends that information back to the Outreach server over a cellular network. The Outreach server (using server-side software written by volunteers), collects and integrates speed data from numerous sources (including Caltrans and 511). The PDA data is collected by the Outreach server and stored as "virtual loop detector" files that hold real-time and historical speed data for major highways, main arterials and streets. The data archive is used to forecast roadway speeds for each segment. The information was made available on a public website and planned to be provided to the 511 system as well.

The probe software and communications have been verified by the vendor to work with a Pocket PC (Windows Mobile 2003) with either a CDMA or GPRS internet connection. The users may choose to remain anonymous or have a unique ID attached to their information and obtain usage data. The vendor claims to have successfully tested the probe aspect of the project with the following user hardware:

- HP IPAQ Navigation system running on HP 6215 PDA
- Audiovox PDA VX6600
- AVL Bluetooth GPS Receiver (BT-15)

3.2 Previous Evaluations (including vendor's own) and/or Similar Technology Deployments

A number of studies and operational tests have been conducted in the US in the past decade to explore the possibility of cellular phone-based probe technology. This section summarizes these efforts and the major findings.

CAPITAL Field Operational Test (UMD, 1997)

The Cellular APplied to ITS Tracking And Location (CAPITAL) test was conducted over a 27-month period in the mid-90's on several interstates and state routes in Virginia. The test's findings include:

1. Cell phone could be located within 100 meters of the actual position.
2. Link speed could not be generated from the test due to a small number of data points and lack of algorithms to match vehicles to roads.

The test of cell phone based traffic probe data was not successful in this test.

US Wireless Operational Tests (UC Berkeley, 2001)

Researchers from UC Berkeley obtained 44 hours of wireless location data in Oakland provided by US Wireless Corporation (no longer in business) and found that:

1. The position estimates generally had 60-meter accuracy, although 66% of all probe vehicles tracked had at least one data point that deviated from the caller's actual position by more than 200 meters.
2. The tests were not successful in matching vehicles to roads or generating speed or travel time information. 60% of vehicles could not be matched to a roadway link.
3. Median communication length was about 30 seconds, which was not sufficient to estimate speeds

UC Berkeley Operational Study (Cayford and Johnson, 2003)

In this study, the researchers examined three operational parameters affecting the use of anonymous cell phone tracking for generating traffic information:

1. *Location accuracy*- The test found that the location technology with 100-meter accuracy can determine the correct road for 98.4% of all surface streets and 98.9% of all freeways. A technology with 50-meter accuracy can determine the correct road for 99.5% of all road segments.
2. *Frequency of position update*- Reduction in the frequency of position update reduces the accuracy of road identification. For location technology accurate to 50 meters, the percentage of correct road identification fell from 99.5% at update frequency of every 1 second to 98.8% at update frequency of every 30 seconds, and 98% at update frequency of every 45 second.
3. *Number of locations that could be determined per second per square mile*- The number of probe locations available at a time impacts the geographic coverage of traffic data. This study found that the percentage of roads covered increases as the number of locations per second per square mile increases.

Virginia DOT – Maryland State Highway Administration – US Wireless Corporation Test (Smith, et.al., 2003)

This test was participated by multiple agencies and cellular providers on the Washington D.C. area Capital Beltway and many other arterials. The test results were:

1. Cell phone probe was unable to reliably estimate conditions on low-volume/speed urban links.
2. Cell phone probe systems are not ready to provide the accuracy and availability needed by modern traffic management system due to large required sample size and limited accuracy.

Private Sector Provision of Congestion Data Probe-based Traffic Monitoring State-of-the-practice Report (NCHRP Project 70-01, University of Virginia, November 1, 2005)

This report summarized a literature review of 16 wireless location technology deployments around the world and drew the following conclusions:

1. Initial deployments did not produce data of sufficient quality or quantity to provide reliable traffic condition estimates. More recent deployments appear to produce better data, but there is not enough information to completely characterize the quality of the data.
2. While performance of these systems has been demonstrated to a limited degree on freeways, there is very little experience on monitoring arterials.
3. In general, the simulation studies have shown that Wireless Location Technique (WLT)-based systems can conceptually produce good performance for simple networks. Performance appears to worsen for more complex networks, illustrating the need to use well-developed map matching and data screening methods.
4. Most recent WLT deployments rely on cell handoff data, as opposed to “direct” vehicle location determination. Despite this, no published simulation studies have explicitly examined a handoff based WLT system.
5. In a number of cases, inadequate sample sizes were generated to produce accurate speed estimates. This problem appears to be most pronounced in the off peak hours, such as the middle of the night.
6. Transportation agencies have historically not defined detailed performance requirements for these systems. Prior to using this technology, an agency should ensure that requirements are in place to support the transportation applications for which the data will be used.
7. Many deployments have lacked a well-developed, independent evaluation that quantitatively assessed the system performance. Future deployments should include an independent evaluator that will examine the availability and accuracy of the data.
8. Many of the institutional and legal issues are not clearly defined in past deployments. Likewise, financial and contractual information is also not often available in the literature. More information on these areas is needed to help assist agencies that are entering into contracts with providers of this technology.

3.3 Cost

There are both vehicle costs and system costs associated with a probe vehicle system. For a cellular-phone based system, the user costs are minimal as cellular phones are prevalent among motorists. For a PDA/GPS-based system, the user costs include the GPS receiver, a PDA device, cellular-service modem (may be included in the PDA device) and recurring network access/data transmission fees. For the Baltimore and Portland deployments these vehicle costs were incurred by FedEx and TriMet, respectively. No information is available regarding these costs. For the San Francisco Bay Area deployment, it is estimated that each user paid $100 for the GPS receiver and connecting equipment to the PDA. The PDA was owned by the volunteer and it is assumed that the data was transmitted via existing cellular modem with an unlimited data plan.

System costs that are borne by the agency include initial deployment costs as well as on-going maintenance costs. Initial deployment costs include server hardware and software costs, as well as system configuration costs. On-going maintenance costs include payments to the cellular phone provider for processing/accessing cellular phone data use, as well as costs associated with maintaining the hardware and software. There is no information available from these deployments on these costs.

4. Performance Measures

Performance measures for this project are defined here and divided into different categories for evaluation and discussion: Quantitative, Qualitative, and Other Performance Factors. Quantitative measures cover the aspects of performance that can be reflected with any available performance data. Qualitative measures cover the aspects of performance that has equal significance but cannot be compared with numbers. Other performance factors discuss issues not addressed by quantitative and qualitative measures but may influence the technology's future deployment.

Definition of Performance Measures

For this report, the purpose of probe vehicle technology is to collect accurate data regarding roadway speeds, integrate this data source with data collected from other sources (e.g. fixed loop-detector stations), and provide real-time and forecasted speeds and travel times.

4.1 Quantitative Outputs

Coverage

1. *Are deployment locations balanced between freeways and arterials?* ☒ YES ☐ NO

Generally, the traffic probe technology is aiming at expanding traffic data sources to target freeways and arterials. Some of the deployment tests cover freeways only, such as the deployment test on Interstate 75 in Atlanta. Some of

the deployment tests cover arterials only, such as the transit vehicle AVL probe test in Portland. Other deployment tests cover both freeway and arterials, such as the probe test in Baltimore.

2. *Are probes balanced between urban areas and rural areas?* ☐ YES ☒ NO

Generally urban areas have more vehicles and thus have more potential probe vehicles. Most of the deployment tests are focused on urban areas with heavy traffic volumes. The Missouri deployment eventually planned to expand the system statewide.

3. Are probes balanced between peak periods and off-peak periods? ☐ YES ☒ NO

Generally there are more vehicles during peak periods and thus more potential probe vehicles during this time; however, it is feasible that these systems could be applied to off-peak periods assuming that enough probes could be available.

Accuracy

1. *Does this data improve upon the accuracy of an existing regional traveler information system?*
None of the deployment locations have integrated the traffic data collected from the probe vehicles in their regional traveler information system.

2. *Can the system differentiate between SOV and HOV speeds?*

Cellular-phone based: ☐ YES ☒ NO
GPS/PDA- based: ☒ YES ☐ NO

The cellular-phone-based systems evaluated are not capable of differentiating the speeds between the SOV and HOV lanes on a freeway, as this level of detail is beyond the granularity of the data examined. The GPS/PDA-based systems evaluated did not differentiated between SOV and HOV speeds either. However, according to Outreach, with the utilization of Differential GPS (DGPS) and adjustments to software, their system is able to determine the lane position of the vehicle.

3. *Can the system differentiate between arterial and freeway speeds?*

Cellular-phone based: ☐ YES ☒ NO
GPS/PDA- based: ☒ YES ☐ NO

For the cellular-phone-based systems evaluated, this would depend on how close the arterials and freeways are to each other and how parallel the arterial and freeway section are run. Generally, the cellular-phone-based systems are

not capable of differentiating between the speeds of freeway and a parallel arterial, as this level of detail is beyond the granularity of the data examined. For a GPS/PDA system, the location of the vehicle within 30 feet; this would typically be accurate enough to determine whether the vehicle is on a freeway or parallel arterial.

Reliability

1. *What are the main difficulties in data aggregation for probe technologies?*

   From the literature review, the main issue with data aggregation involves validating the individual data points and addressing duplicate, conflicting, and erroneous data. None of the evaluated locations provide details regarding their methods for addressing this issue.

2. *How are erroneous probe device transmissions, possibly resulting from non-existent, fragmented or faulty data, handled by the system?*

   The deployments did not elaborate on how errors due to faulty data were handled. The Outreach report stated that their high speed database was originally designed to hold millions of data points with the ability to contain over 240,000 continuous data streams of information, archiving over 20 times per second. Error data processing should be a standard feature included in the database software package. Other deployment tests did not elaborate how error handling was conducted.

Cost

1. *What is the monthly user cost of wirelessly transmitting the data sent by the average probe user to a central server?*

   For cellular-phone-based systems, there is no monthly user cost for this. There was no information provided for the PDA/GPS-based systems in Baltimore and Portland. For the San Francisco Bay Area, deployment, it was assumed that volunteers transmitted the data by utilizing existing unlimited data plans. A typical monthly charge for this is approximately $20-$30 (on top of an existing standard voice plan).

2. *What is the minimum cost of the equipment required for probe device users?*

   For cellular-phone-based systems, there are minimal costs assuming that cellular-phone market penetration is sufficient. For a PDA/GPS-based system, the user costs include the GPS receiver, a PDA device, cellular-service modem (may be included in the PDA device) and recurring network access/data transmission fees. For the Baltimore and Portland, deployment costs were incurred by FedEx and TriMet, respectively. No information is available regarding these costs. For the San Francisco Bay Area deployment, it is estimated that each user had to pay $100 for the GPS receiver and connecting equipment to the PDA. The PDA is owned by the volunteer and it is assumed that the data was transmitted via existing cellular modem with an unlimited data plan.

   The Outreach report mentioned plans for providing their post-processed real-time and predicted travel time information to users for a $20 per month fee (not including the wireless connection and data transmission fees.) This plan has not implemented.

Productivity

1. *What is the lag time between when the data is measured by the probe device and when it is utilized in the roadway conditions map and forecast?*
   In the test deployment in Missouri, cell phone probe traffic data collected with assistance from Cingular had a latency of 2.5 minutes. No information was available for the other deployments.

2. *What is the maximum number of roadway segments that can be tracked at the same time?*
   The system report by Outreach indicated that during the test, there were 900,000 Virtual Loop Detections in the system, but the maximum number was not reported. No information was available for the other deployments.

3. *What is the maximum number of simultaneous communications from probe devices that the system can handle?*
   This information was not available for any of the examined deployments.

4. *Is the procedure that is used to calculate segment speeds accurate?*

   The Portland system reported successfully determining roadway speeds based on transit-vehicle probe data in an initial test deployment. However, there have been no further tests or actual deployment of the system, and this claim could not be verified. The Baltimore system is currently under evaluation so data is not available. The Outreach system was discontinued prior to evaluation so data is not available from this demonstration either.

5. *Is the system capable of providing route travel time information?*
   Only the San Francisco Bay Area deployment included forecasting roadway speeds for purposes of disseminating travel time information. Forecasts were based on real-time data and four weeks of historical data. The forecasts were updated 12 times an hour, or approximately every five minutes. The Outreach system report includes one travel time comparison where the forecasted travel time was compared with travel time from another source, MapPoint 2004. For a road section of 20.93 miles, Outreach system forecasted the travel time to be 35.96 minutes while MapPoint 2004 gave 27 minutes without counting real time information. From this example, it appears that the Outreach system travel time forecasts consider more than just distance. The accuracy of the calculation was not verified. This feature and its accuracy could not be verified since the system was discontinued prior to this evaluation.

6. *How often is the data transmitted from the probe to the server?*
   During the deployment test of traffic probes using transit vehicles in Portland, the probe vehicles' precise location (latitude-longitude) were recorded every 3 seconds. No information was available for the other deployments.

7. What is the duration of historical data that is archived and utilized in forecast roadway speeds?
   Only the San Francisco Bay Area deployment included forecasting roadway speeds. According to the Outreach system report, the system archives and uses four weeks of historical data to forecast roadway speeds

8. Are all highways and major arterial streets included in the database?

   ☐ YES ☒ NO

   The Outreach system report states that this test covers only major corridors. Other previous tests were not full-scale deployment either and only covered sections of major highways or arterials.

4.2 Qualitative Outputs

Accuracy

1. *What speed data sources are utilized in the probe vehicle system website?*

   Only the San Francisco Bay Area deployment included integration of the probe vehicle data with other data sources. According to the system report by Outreach, the system uses Caltrans data collected from magnetic loops and data from MTC.

2. *What is the accuracy of the probe data collected for freeway and arterials?*

   Accuracy is the most critical factor in evaluating the feasibility of the traffic probe technology. Different deployment tests yielded different results. For the deployment test in Baltimore, its primary staff indicated that arterial probe data accuracy needs to be improved before it can be used to produce traveler information the public can use. The reason is that traffic on arterials has numerous unpredictable traveling behaviors, such as turning and stopping, which makes the calculation of average traffic speed difficult. Compared to arterials, traffic probe data collected on freeways was more accurate.

   The deployment test in Portland used buses as probe vehicles. Since buses make many stops along the arterials, the test team decided to use the highest speed of the buses between stops and established a relationship between the highest bus speed and the actual average traffic speed with statistical analysis. The resulting accuracy was reported as satisfactory.

Reliability

1. *Is the data transfer from PDAs or cell phones to the server secure?*

   Data security is a major concern for the traffic probe technology. Every deployment test needs to address this issue carefully. For the deployment test in Atlanta, data was collected by cellular service provider and then encrypted and sent to data server for processing. For the deployment tests in Baltimore and Missouri, similar data filtering was applied for data security. Despite these security measures, the cellular provider discontinued participation in the test to ensure that there was not a customer perception of data insecurity. For the deployment test using PDA/GPS in Portland, Baltimore, and the Bay Area, fleet vehicles were chosen to be probe vehicles so that data security was not a major concern.

2. *Is the PDA software compatible with different manufacturer PDAs?*

   The Outreach system software was developed by volunteers for AudioVox 6600 PDA. It has not been tested for other types of PDAs. Considering that most of the commercial off-the-shelf PDA software is compatible with all types of PDAs, traffic probe software that is compatible with different types of PDAs is technically feasible with additional software development.

3. *Is the PDA software compatible with different GPS NEMA versions?*

   The software was developed by volunteers for Nav GPS, but the software was written to automatically detect different protocols used in different GPS NEMA versions.

4. Is the system capable of handling more probes in the future? Is the system scalable?

   According to the Outreach system report, the Virtual Loop database has the ability to accommodate a very large number of data streams such as electric power grids for the California Independent System Operator as well as 10,000 other large systems worldwide. It has the ability to expand to handle larger probe data in the future.

5. *Is the system capable of accepting data from other public agencies?*

   The Outreach system report states that it received data from Caltrans and MTC during the demonstration.

6. Are real-time and forecasted speeds available through a single website?

   ☒ YES ☐ NO

   All the information was available from www.realtimetraffic.org during the test period. This website is no longer available.

7. Is the forecasting algorithm capable of being further developed? ☒ YES ☐ NO

   According to the Outreach system report, additional software development is anticipated to expand the capabilities. This development will be dependent on available funding sources.

Cost

1. *What are the costs associated with PDA equipment?*

   The probe user must have a compatible PDA device with a network connection and a GPS unit. The cost of this equipment is estimated to be $300 to $500 per vehicle.

2. *Is the probe user responsible for cellular fees resulting from data transmission?*

   In the cellular-phone-based-systems, users did not need to pay the fee for transmission of the vehicle location information to the server.

Productivity

1. *Are privacy concerns satisfactorily addressed?* ☐ *YES* ☒ *NO*

   Cell-phone probe deployment can attract a lot of media attention regarding the potential privacy invasion. The cell probe deployment in Missouri tried to address the privacy concerns in two ways. First, the agency explained the great benefit of cell probe technology to the traveling public in terms of the ability to develop useful traveler information. Second, all privacy sensitive data has been filtered off by the cellular provider before it reaches any agency or

private sector stakeholders so the data can not be tied to a specific cellular phone.

2. *Does the inability to distinguish between HOV and SOV greatly diminish the benefit provided by the system?* ☐ YES ☒ NO

   The most important feature about cell probe technology is that its deployment can provide substantial freeway and arterial traffic information that can not be obtained from existing sensors. Most HOV lanes are on freeway sections in the busiest urban areas, and are equipped with traffic surveillance already. Cell probe traffic data aggregated with data from other surveillance sources will provide more comprehensive traffic information to the public.

3. *Is the data generated by probe devices capable of benefiting a regional traveler information system?*

   Literature research shows that probe data will benefit regional traveler information systems by adding more data sources and improving data accuracy.

4. *Is the traffic conditions interface on the website user friendly?* ☒ YES ☐ NO

   Outreach was the only deployment that provided a user website. According to the Outreach system report, the traffic speed data was provided on electronic maps with a standard GIS user interface with functions such as Pan and Zoom. Traffic conditions were displayed in different colors for easy reading.

5. *How robust is the data storing capacity of server?*

   According to the Outreach system report, the database is the same as used to control the electric power grid for the California Independent System Operator as well as 10,000 other large systems worldwide. It is a powerful database designed to accommodate large-scale data streams.

6. *Is it possible to determine vehicle speed per lane using GPS technology?*

   ☐ YES ☒ NO

   Current traffic probe technologies have not been able to reach sufficient location precision to identify lane information. According to the system report by Outreach, lane information can not be differentiated with this system.

7. Do the users need extensive programming knowledge to operate the GPS/PDA equipment? ☐ YES ☒ NO

   According to the system report by Outreach, users do not need more skill than normal PDA and vehicle onboard GPS operations.

8. *What was the sample size for used for this pilot demonstration?*

   Information from 5000 road segments was collected and processed for the Outreach deployment test. No information was available regarding the other deployments

9. *Does the presence of PDAs and cell phones cause in-vehicle driver distraction?*

   ☐ YES ☒ NO

   Most current probe technology is "hands off" and does not require active participation by the user during monitoring and data transmission.

10. *How do these performance measures relate to Caltrans' 9 Performance Measures?*

    Caltrans' performance measures are used to assess the operations of multi-modal transportation systems in order to create a more accountable framework for decision making. The following table relates the project performance measures against the Caltrans performance measures.

	Caltrans 9 Performance Measures								
	Mobility/Accessibility/ Reliability	Productivity	System Preservation	Safety	Environmental Quality	Coordinated Transportation and Land Use	Economic Development	Return on Investment	Equity
Outputs Measured									
Accuracy	✓								
Cost	✓							✓	
Reliability	✓								
Productivity	✓	✓		✓				✓	

Scalability

1. Is the system scalable? ☒ YES ☐ NO

   The limitation of expanding such systems is communications bandwidth between the probe vehicles and the processing server and processing power.

Both of these can be addressed easily by scaling up the end equipment. According to the Outreach system report, the system can be easily expanded to cover the entire Bay Area.

4.3 Performance Factors

Enhancing Advanced Traveler Information System

If successfully deployed, traffic probe data could benefit the advanced traveler information system by providing much more extensive and comprehensive traffic data on both freeways and arterial networks. Such information could improve network efficiency (routing traffic around incidents) and overall safety.

User technical expertise

For the cellular-phone-based systems, no technical expertise is required from the user. The only requirement is the ownership and maintenance of a cellular phone and leaving it on. For the PDA/GPS-based deployments, the user technical requirements are higher. For the Baltimore and Portland deployments, this equipment would need to be maintained by organizational IT staff. For the San Francisco Bay Area deployment, the PDA software requires some technical expertise and willingness of the volunteer user to install and configure the PDA software, as well as troubleshoot the connection to the GPS receiver and cellular phone connection. This approach may limit the adoption of the system although there appears to be adequate technical support.

System technical expertise

All the deployments require substantial technical support at the system end in order to set-up the data gathering and processing functions. It is unclear if agencies will have the resources and capability to maintain such a system, and may need to rely on paying an outside consultant to maintain the system.

5. Evaluation Methodology

The performance measures described above were planned to be evaluated in the following ways.

1. **Conduct literature research on probe vehicle technologies, focusing on issues regarding:**
    a. **Privacy invasion**
    b. **Technology**
    c. **Equipment requirement**
    d. **Travel time forecasting**
    e. **Scale of probe for optimum data quality**
    f. **Traffic data accuracy**
    g. **System maintenance**
    h. **Incident detection**
    i. **Cellular providers**
    j. **Lessons learned from earlier deployment tests**
    k. **User charge and system cost**
    l. **System standard and proprietary system interoperability**

2. **Based on the literature review, identify current and planned deployments of probe vehicle technologies for the purposes of obtaining real-time traffic data.**

3. **Contact the agencies and consultants of the identified deployments to discuss status and deployment issues.**

4. **Obtain evaluation results from deployments (if available).**

6. Evaluation Results

The following results were obtained based on a literature review, and contact with the deployment agencies (when available)

Atlanta, Georgia deployment (cellular phone-based)
Repeated phone calls to GDOT were not returned. Additional information could be gathered from GDOT regarding the system deployment and/or evaluation.

Baltimore, Maryland Deployment (cellular phone-based, GPS-based on fleet vehicles)
The SHA Project Manager, Mr. Glen McLaughlin, was contacted regarding their system deployment and gave the following general comments:

- The cellular phone-based part of the project was discontinued after a short time. Delcan (contracted consultant) had an agreement with Cingular (cellular service provider) to provide data (stripped of sensitive and identifying information) for Delcan's real-time analysis, but Cingular discontinued the service due to users' concern over the perception of privacy invasion and data abuse. It appears that privacy disclosure was technically impossible, but Cingular made this decision to protect the company's image and prevent any potential user concern from happening.
- The PDA/GPS-based part of the project used fleet vehicles (such as FedEx) where privacy issues were not a concern. The data accuracy appeared better for freeways than for arterials. Arterial probe data is probably unreliable due to highly unpredictable driver behavior on arterials.
- The accuracy of probe vehicle data on freeways was compared with data from fixed sensors and against floating car surveys, but these results were hard to compare directly. Fixed sensors provide "point speed" while probe data is "segment speed", and "floating car" surveys were not reliable due to very small sample size and high variance.
- Generally, Mr. McLaughlin believes that probe technology has great potential in future but recommends more research on this new technology and clear/reasonable definition of expectations before any large scale deployment takes place in any area.
- University of Maryland (UMD) is preparing a formal evaluation report that scheduled to be released in 2006. This report was scheduled to be completed in July 2006, but as of the date of this evaluation, the report has not been completed.

Missouri (cellular phone-based)
The MoDOT Project Manager, Michelle Teel, was contacted regarding their system deployment and had the following comments:

- The system has not been deployed since Cingular (cellular service provider) has pulled out of their agreement with the Delcan (contracted consultant). Delcan is trying to find another cellular provider to conduct this project, but has not found another provider as of our conversation with Ms. Teel in August 2006.

- The biggest issue MoDOT has encountered so far is appeasing public concerns and media attention over privacy issues. MoDOT successfully addressed these issues by showing the public the results and benefits of this technology and demonstrating that the data is anonymous (all personal information is filtered by cellular provider before it is delivered to Delcan and MoDOT).
- Kansas DOT has currently deployed a small scale cellular phone-based probe demonstration project in Kansas City (across the border from Missouri) and the data is reported to be accurate despite a 2.5-minute latency.

Portland, Oregon (GPS-based on transit vehicles)
ODOT was contacted regarding their system deployment. The have been no further tests or actual deployment of the system after the preliminary investigation in 2003, possibly due to resource challenges. The preliminary study included the following information:

- Travel speed of buses reported by AVL and that of GPS-equipped "floating cars" were compared during peak periods for two days.
- The study established a relationship between the bus travel behavior and the passenger car speed using statistical methods with maximum instantaneous bus speed being about 0.72 times the floating car vehicle speed.
- The report concluded that further analysis for a longer period and larger scale was needed to provide a greater level of confidence to the study results.

San Francisco Bay Area, California (GPS-based on volunteer vehicles)
Outreach led an effort to place PDA/GPS-based probe vehicle systems on volunteer vehicles from August 2005 to November 2005. The system was shutdown shortly after the 2005 ITS World Congress and could not be evaluated. Outreach provided a system report that was previously written that focused on technological details of how the system was developed but not on whether it worked as planned. The report indicated that the traffic information can be obtained from probe sources to be displayed on the website. The Outreach system's accuracy, reliability, feasibility and other performance factors discussed in this evaluation report are mostly derived from the Outreach report and could not be independently confirmed as part of this evaluation.

Key Observations
Based on the information gathered, cellular-based and PDA/GPS-based traffic probe technology is feasible and offers the potential for an additional source of real-time traffic data for roadway agencies. However, there are some critical issues with this technology that need to be addressed for this technology to realize its potential.

Accuracy
Based on the evaluation locations, there is uncertainty regarding the accuracy of probe vehicle data in reflecting general roadway conditions.

AirSage claimed in a test deployment in Atlanta that their "data is nearly always categorically correct," meaning that traffic can be categorized as moving fast, medium or

slow relative to normal conditions and planned second level of implementation would be enhanced to within a few mph. Phone calls to GDOT were not returned and this claim could not be verified. Outreach did not include a discussion of accuracy in the system report. The Baltimore, Maryland, system is currently under evaluation.

Privacy Issues

The idea of using cell phones or PDA/GPS system to track vehicles will immediately raise privacy issues in the public. This is a very sensitive issue for the agencies and companies involved in these deployments. These deployments dealt with the privacy issue in different ways. For cellular-phone-based systems, typically the cellular service provider filters all sensitive data before it is delivered to the data server. For the Outreach system, participating volunteers could choose to send the probe data anonymously. Baltimore and Portland used FedEx and TriMet vehicles where privacy is less of a concern.

Despite these measures, the Missouri and the cellular-phone-based part of the Baltimore deployments were halted because the cellular service partner pulled out of the project in concern for bad publicity. Privacy is a very sensitive public relation issue and needs to be well communicated with public and media.

Private Partners/ National Standard

Despite the interest and investment in traffic probe technology around the country, there is not a national standard regarding what data can be exchanged as well as its format. Currently much of the deployed systems rely on proprietary software and negotiated agreements between one agency and one data provider. Developing such a standard would be important to ensure a sufficient pool of private partners.

Economic model

Since most of the deployment tests regarding the traffic probe technology at the current stage are still focused on the accuracy of traffic data collection, there has not been a completed business model built to analyze the economic feasibility of actual deployment. A recent survey by Driscoll-Wolfe investigated 14,000 cellular subscribers and reported that 37% of them would like personalized traffic alerts, and 12% of them would pay $2.50 to $5 per month for this service, given most people already have cell phones. The Outreach report mentioned providing their post-processed real-time and predicted travel time information to users for a fee of $20 per month not including the wireless connection and data transmission fees. Further feasibility studies regarding the willingness to pay for this service is needed before larger scale deployment.

7. Recommendation to Caltrans

PROS	CONS
Traffic probes present the opportunity for another source of traffic data.	Algorithms for correlating probe data to roadway speeds and travel times still under development.
Less calculation required to determine travel time of an individual vehicle for a segment.	Dependent on sufficient volume of probe vehicles to produce accurate and reliable data.
Installation of equipment is less disruptive and less expensive than installation of loop detectors or other point-based vehicle detection devices.	Public will have privacy concerns about probe technologies.
Relies on existing cellular networks and/or GPS so can be deployed to cover a larger area quickly.	Privacy concerns may limit the willingness of cellular phone providers to be associated with cellular-phone-based tracking.
System could cover arterial streets network which is typically not as monitored by traditional traffic monitoring technologies	Currently, GPS-based devices are not common among drivers.
Cellular phones are common among motorists. GPS-based devices (including new cellular phones) are becoming common	Lack of a standards or protocols for data exchange increase costs for agency to switch to new probe vehicle provider.
Opportunity for private/ public partnership.	

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ITS Pilot Project Demonstration

SPEEDINFO
Evaluation

Prepared for
Caltrans

June 2006
FINAL

Prepared By
Kimley-Horn and Associates

ITS Pilot Project Demonstration

SpeedInfo

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Evaluation Summary

This section summarizes the major findings of the evaluation of the SpeedInfo/ Speed Sensor Demonstration Project. Additional details regarding the evaluation can be found following this section and in the evaluation appendices. The Vendor provided comments on the FINAL draft evaluation and applicable comments are summarized in the following section.

Vendor/Project – SpeedInfo/Speed Sensor Demonstration Project

SpeedInfo uses Doppler radar technology to obtain speed data. The data is then transmitted to a central server via a cellular network. SpeedInfo then reviews the accuracy of the data and formats it for delivery to their partners. This data is available on the SpeedInfo website at http://traffic.speedinfo.com.

Delivery: Does demonstration satisfy Vendor's stated objectives for Caltrans?

Reduce data collection costs by more than 90% ☒ YES ☐ NO

Provide accurate speed data up to 500 meters (1640 feet) away ☐ YES ☐ NO ☒ NOT VERIFIED

This Vendor claim was not verified. According the Vendor, the distance between the sensor and the roadway measurement area for most Bay Area installations is usually between 400 to 600 feet, and there may be one or two locations where this distance is 1500 feet (on Interstate 280). At the evaluation location, the distance between the sensor and the roadway measurement area is 750 feet according to the Vendor, Caltrans latitude/longitude information and field survey.

Continuous data provision (24/7) ☒ YES ☐ NO

SpeedInfo provides data continually so long as the roadside unit, communications links and SpeedInfo servers are operating.

Key Observations

- **According to the Vendor, several considerations are taken into account when determining a sensor installation site. The main considerations are orienting the sensor to adequately capture specific traffic flow patterns; and have acceptable cellular signal levels 30 feet in the air. Proper solar panel orientation and exposure is also important, with the solar panel typically facing the south side sun.**
- **It typically takes 20 minutes for two people to install the sensor equipment at a particular location with one person communicating with the server**

station and the other person installing the equipment on a pole with the help of a bucket truck.

- **This evaluation compares Caltrans speed data (dual-loop station), SpeedInfo speed data (Doppler radar speed sensors) and speed data from a single probe vehicle in mixed-flow lanes during peak period. While these data sources are gathered using different methodologies (with differences in specific results), there is an overall correlation between their results.**
- **The sample size for comparing SpeedInfo data and Caltrans data was 2758 points in the westbound direction and 2278 points in the eastbound direction. When comparing 30-second samples of SpeedInfo data to Caltrans loop data for eastbound and westbound directions at the evaluation location[1], 90% of the eastbound SpeedInfo samples were within 20% of the Caltrans speed, and 50% of the westbound samples were within 20%. When speeds were lower during the AM and PM peak periods, fewer SpeedInfo samples were within 20% of the Caltrans loop data and GPS ground truth.**
- **It appears that the difference between the SpeedInfo data and Caltrans data increased as speeds decreased in the westbound direction. When Caltrans speeds were below 40 mph, the average difference between SpeedInfo and Caltrans was about 45%. Speeds of less than 40 mph were observed during the AM and PM peak periods. This was not the case in the eastbound direction although the Caltrans speed only dropped below 20 mph twice.**
- **In addition to the different data collection methodologies, possible reasons for the differences in speed measurements could include the following:**
    - ***Spatial difference between the SpeedInfo measurement area and the location of the Caltrans loops.*** **The westbound Caltrans loops appear to be approximately 750 feet upstream and downstream of the SpeedInfo measurement area, while the location of the eastbound Caltrans loops could not be verified through latitude/longitude information or field survey. The traffic patterns in this vicinity can be unstable[2] resulting in different speeds being measured by Caltrans and SpeedInfo.**
    - ***Stop-and-go traffic conditions.*** **During stop-and-go conditions, vehicle speeds vary more significantly. At one point in time, cars may be traveling at 15 mph and a few seconds later they may be traveling only 2 mph. The impacts of such variability are typically more averaged out by loop stations.**

[1] Interstate 80 between Golden Gate Fields and Gilman Avenue on December 7th from 6:00 AM to 6:00 PM and December 8th from 7:00 AM to 6:00 PM

[2] I-580 and I-80 merge in the westbound direction and diverge in the eastbound direction.

- ***Impact of HOV lane traffic.*** **Both the Caltrans loop data and SpeedInfo sensor data include HOV traffic when calculating overall speed, while the probe vehicle traveled in mixed-flow lanes and is based on a single vehicle measurement.**

- **At several points during the evaluation period (January, February, and March, observations were made of the *traffic.speedinfo.com* website to observe the number of locations that were not reporting "recent" information. At the beginning of the evaluation period, there were about 50 locations (25 sensors) that were not reporting information. It was assumed that most locations are collecting data in both directions so each direction is counted as one. The sample size was a total of 25 random observations during the evaluation period. These failures could be intermittent but for the most part appeared to be the same locations that were not reporting in each observation.**
- **After the first set of observations, the Vendor indicated that crystal devices in about 100 SpeedInfo sensors had malfunctioned, and that they were replacing 15 crystal devices every week. There was a noticeable decrease in the number of device failures observed. However, observations in March and June have shown that the number of units "not reporting" is averaging more than 25 sensors out of a total of approximately 300 devices.**
- **According to the Vendor, the following problems were encountered during deployment that affected the ability of sensors to report and/or collect data:**
  - **Electronic noise**
  - **Faulty parts (including crystal devices, see below for more detail)**
  - **GPRS communications failures**
  - **Water leakage.**

Recommendation to Caltrans

The following table represents pros and cons that were observed and noted during this evaluation. The reader or end user should consider this information against the specific application to determine if this product can provide the desired solution.

PROS	CONS
Provides ability to access speed data at locations without data infrastructure in place.	Currently provides only an average speed per sample size. Devices do not provide volume, occupancy and density data provided by loops.
Low power requirements and runs on solar power.	Does not break down data per travel lane.
Ease of installation and configuration into an existing SpeedInfo system.	Crystal clock device failure and other failures cannot be predicted. (Issue appears to have been resolved.)
Uses proven Doppler technology.	
Installation cost is a fraction of the cost to install inductive loop stations on both sides of the road.	
Flexibility in adjusting the location of speed measurement area.	
Easy data access for public via website.	

Evaluation Details

1. Delivery

Vendor's Stated Objective
In Caltrans contract: r *Provide real-time data feed* r *Low-Cost* r *Hundreds of sensors deployed* r *Provide data to CalTrans and 511* r *500-meter range, Bi-directional and multi-lane* *Additional Assertions:* r *Reduce cost by 90% to $600 per sensor* r *Commercial quality service 24x7* r *Can withstand weather elements*

2. Project Specifics

Deployment Date(s) and Time(s)	Evaluation Date(s) and Time(s)
285 units installed between June 13, 2005 through October 27, 2005	**December 7th and 8th, 2005** **7 AM to 6 PM** **Weather: Sunny**
Deployment Location(s)	Evaluation Location(s)
San Francisco Bay Area: **SpeedInfo sensors have typically been installed at locations where Caltrans loops do not exist in the Bay area. There are a few SpeedInfo sensors that have been installed where Caltrans loops are nearby. A sample from one of these locations was used in the evaluation.**	**1. I-80 E between Gilman St. and Golden Gate Fields** **2. I-80 W between Golden Gate Fields and Gilman St.**

3. Technology

3.1 Technology or System Description

SpeedInfo's DVSS-100 Doppler Vehicle Speed Sensor is a fully self contained, roadside mounted, vehicle speed measurement sensor. The DVSS-100 uses a 24 GHz Doppler microwave transceiver system coupled to a Digital Signal Processor to measure and calculate vehicle speed. The DVSS-100 is capable of determining average or composite vehicle speed for a multiple lane freeway or highway. Speed information is backhauled to SpeedInfo's data server over a GPRS cellular data link. See Appendix A for the Vendor specification sheet.

SpeedInfo collects data from their traffic sensor locations and merges that with publicly available traffic data in order to process the data and format it for the end user. The formatted speed data can then be sent to a variety of end users including:

- Caltrans
- 511 System
- Emergency Vehicles
- Cell phones
- Digital radio (future distribution)
- Private vehicles with navigational/GPS software (future distribution)
- Commercial fleets/trucking

3.2 Previous Evaluations (including Vendor's own) and/or Similar Technology Deployments

This technology is currently being deployed in several areas around the country. It is not known if these deployments have been evaluated by the agencies that are using them. At the beginning of the evaluation period, the Vendor stated that they continuously evaluate and calibrate sensors in a lab using rivets placed on a moving belt at 36 mph while the sensor computes and transmits the data. Since the completion of the evaluation, the Vendor has indicated that the belt assembly has been replaced with a signal generator for Doppler testing. Vendor claims that sensor is calibrated to be accurate to within 1/10th of a mph. This was not confirmed as part of the evaluation.

3.3 Cost

The total installed cost is less than $5,000 per SpeedInfo station, according to the Vendor. One SpeedInfo station provides coverage for both sides of the road. Recurring costs include a monthly service cost for the cellular data service and routine maintenance. The Vendor claims that maintenance is relatively low because the units are constructed to withstand weather elements.

The typical Caltrans cost for installing a new loop location covering both sides of a road is $65,000. Replacing existing loops or installing other non-intrusive equipment costs $20,000 to $25,000 for one side of the road. This estimate does not include traffic control costs (which could be substantial depending on the location).

As part of their business model, the Vendor bears the equipment, installation, cellular communications and maintenance costs necessary to maintain each station. They recoup these costs by charging subscription fees for access to their data. Information regarding the recurring costs and the subscription fee was considered proprietary and not available.

4. Performance Measures

Performance measures are defined here for this project and are divided into different categories for evaluation and discussion: Quantitative, Qualitative, and Other Performance Factors.

4.1 Quantitative Outputs

Accuracy

1. What percentage of SpeedInfo speed readings are within 10% of Caltrans sample data?

   Based on the sample taken on December 7th and 8th, 2005, 20% of the data at location 1 (I-80W Golden Gate Fields and Gilman St) and 53% of the data at location 2 (I-80E Gilman St. and Golden Gate Fields) were within 10 % of the Caltrans Sample data.

2. What percentage of SpeedInfo speed readings are within 20% of Caltrans sample data?

   Location 1 (I-80W Golden Gate Fields and Gilman St.):

   During the AM peak, the speeds were in the range of 8 to 61 mph and 26% of the readings were within 20% of Caltrans loop measurements. During the PM peak, the speeds were in the range of 5 to 68 mph and 11% of the readings were within 20% of Caltrans loop measurements. During mid-day, the speeds were in the range of 49 to 70 mph and 80% of the readings were within 20% of Caltrans loop measurements. Overall, 49% of the speeds were within 20% of Caltrans loop measurements.

   Location 2 (I-80E Gilman St. and Golden Gate Fields):

   During the AM peak, the speeds were in the range of 43 to 68 mph and 74% of the readings were within 20% of Caltrans loop measurements. During the PM peak, the speeds were in the range of 18 to 68 mph and 53% of the readings were within 20% of Caltrans loop measurements. During mid-day, the speeds were in the range of 41 to 68 mph and 88% of the readings were within 20% of

Caltrans loop measurements. Overall, 89% of speeds were within 20% of Caltrans loop measurements.

3. Does the accuracy of each measurement go down as perpendicular distance increases? ☐ YES ☒ NO

   The Vendor claims that as this distance increases, the number of cars captured by the sensor decreases due to roadway geometry, obstruction from trucks, etc. As a result, fewer cars will be used to compute the average speed as opposed to when the sensor is being used for lesser distances. This claim was not verified but could contribute to discrepancies in data under certain scenarios.

4. Is data accuracy consistent to a range of 500 meters (1640 feet)? ☐ YES ☐ NO ☒ UNVERIFIED

   This Vendor claim was not verified. According to information provided by SpeedInfo, the distance between the sensor and the roadway measurement area in the Bay Area is typically between 400 to 600 feet . There may be one or two deployments in the Bay Area (on Interstate 280) where this distance is 1500 feet. For the evaluation location, the distance between the sensor and the roadway measurement area is 750 feet.

5. How does the average speed calculated by SpeedInfo compare to sample data?

   Average speed calculations by Caltrans (loop data) and SpeedInfo were compared every 30 seconds on December 7, 2005. A sample printout of this comparison is included in Appendix B.

6. Are measurements affected by low light or low visibility conditions? ☐ YES ☒ NO

   During early morning or evening time, it is not evident that the measurements are affected by low light or low visibility. Upon review of data displayed during heavy fog or rain, the measurements did not appear to be affected.

7. What is the approximate speed at which the data shows a decrease in accuracy?
   When comparing SpeedInfo data to Caltrans loop data and GPS data, it appeared that the SpeedInfo speed differed more from Caltrans loops and GPS data when measuring speeds of 20 mph and below for westbound direction (more than 25% reduction in accuracy). The eastbound direction had similar decline at low speeds but it was not as significant.

8. How does the SpeedInfo data and Caltrans loop data compare to actual GPS-based test runs data?

   GPS runs on January 18, 2006 were conducted to determine a "ground truth" speed for the roadway locations. This GPS run speed was compared to the Caltrans loop data and SpeedInfo speed measurements for the same locations. A sample printout of this comparison is included in Appendix C. The table below summarizes the results.

	Time of Day	GPS Test Run Speed (mph)	Caltrans Speed (mph)	SpeedInfo Speed (mph)	Caltrans Difference in %	SpeedInfo Difference in %
I-80 WB AT GILLMAN ST	8:30:18	25.8	25.7	32.0	-0.7%	23.9%
	9:01:25	30.5	31.3	18.0	2.6%	-41.0%
	13:37:43	63.1	69.7	62.0	10.4%	-1.7%
	13:58:13	62.2	71.3	54.0	14.7%	-13.2%
	17:07:13	46.5	59.7	58.0	28.2%	24.7%
	17:50:18	45.6	61.7	60.0	35.1%	31.5%
I-80 EB AT GILLMAN ST	8:15:30	55.4	56.3	68.0	1.5%	22.7%
	8:47:44	59.9	52.3	64.0	-12.7%	6.9%
	13:30:42	62.6	57.3	60.0	-8.6%	-4.2%
	13:51:31	60.4	56.0	61.0	-7.3%	1.0%
	16:56:49	28.6	43.0	56.0	50.2%	95.6%
	17:35:50	26.4	26.8	20.0	1.3%	-24.2%

It is evident in this table that the SpeedInfo data was closer to the ground truth when the speeds were closer to free flow. At lower speeds, there was a variance.

Cost

1. What is the cost of cellular and/or any other additional components necessary for the equipment to function?

   This information is proprietary and not available.

2. Length of installation time:

   Vendor claims that it takes less than 20 minutes per site to install unit on existing pole or structure. An installation was observed to take about 15 minutes, including unit calibration and configuration.

Reliability

1. Was traffic disrupted during installation? ☐ YES ☒ NO
2. If yes, what was the length of time of the disruption and/or length of disruption?

   N/A

3. How many units failed during a sample 24-hour period?

   A log of failures file for each unit is maintained by SpeedInfo and could be used to monitor performance. This file records all the communication failures, failed data transmissions, failed units and the duration of their failure, and lag time of data transmission since the time of inception. This information was not available during this evaluation.

4. How many times in a 24-hour period did the communications fail to transmit data?

   See above (answer to question 3)

5. What is the average time that a unit is not functioning?

   See above (answer to question 3)

6. How many times in a 24-hour period was the posted speed limit shown when the speed was too low?

   See above (answer to question 3)

7. Did any devices need to be replaced or repaired during the evaluation? If so, how many and what was the amount of time before the replacement or repair and the cost of the replacement/repair?

   According to the Vendor, problems were encountered during deployment and operation that affected the ability of sensors to report and/or collect data. This included electronic noise, faulty parts, GPRS communications failures, and water leakage. In one specific instance, the Vendor identified that crystal clock devices in about 100 SpeedInfo sensors had malfunctioned, and were subsequently replaced. There was a noticeable decrease in the number of device failures observed as the evaluation period continued. However, observations in March and June have shown that the number of units "not reporting" is an average of more than 25 sensors out of a total of approximately 300 devices.

Productivity

1. What is the lag between the time data is measured and when it is posted to external sources?
   Vendor claims that it takes 3 seconds for the data to be transmitted from the sensor to the server. Since the speed is calculated every 1 minute, the total time from the time data is measured and when it is posted to external sources is between 60 and 90 seconds. This claim was not verified as part of this evaluation.

2. What percentage of the time did SpeedInfo provide a continuous and valid stream of data to 511?
   See above (answer to Reliability, question 3)

4.2 Qualitative Outputs

Accuracy

1. How did a range of speeds affect the accuracy of the device?

   Based on the two locations that were used in the evaluation, how well the SpeedInfo data matches the Caltrans loop data and GPS ground truth appears to be proportional to the speed of traffic flow. The accuracy tends to decrease at low speeds (AM and PM peak hours) and increase at high speeds (mid-day peak hour). This observation holds true for both eastbound and westbound directions.

   It was observed that the difference between Caltrans loop data and the SpeedInfo speed measurements for the westbound direction is considerably higher than for the eastbound direction. The distance of the SpeedInfo measurement area and Caltrans loops on the freeway may be a reason for this discrepancy.

   Additional analysis was performed by setting classifications of speed ranges for SpeedInfo and Caltrans (i.e., 0-15 mph, 15-30 mph, 31-50 mph, and >51 mph "buckets"). The objective was to observe if the SpeedInfo and Caltrans speed observations fell into the same "bucket". It was observed that 63% of the SpeedInfo and Caltrans speed observations fell in the same speed buckets for I-80 westbound at Gilman Street. For the I-80 eastbound at Gilman Street, it was observed that 88% of the SpeedInfo and Caltrans speed observations fall in the same speed buckets.

2. How did a range of volumes affect the accuracy of the device?

   It is not completely clear in this evaluation how the range of volumes may impact the accuracy of the device. During periods of high volume (such as peak hours), traffic speeds are typically slower for non-HOV lanes, but the speeds measured in the HOV lanes are be higher. During periods of low

demand, the measured speeds should be near free-flow levels, but the lower number of data samples (fewer cars) may introduce more variability in the speed measurements.

3. Did an incident and the resulting disruption to traffic have an effect on the accuracy of the data?

   Data not available

4. Is the installation relatively easy? ☒ YES ☐ NO

Additional Observations:

A "moving window" concept was also tested to see if there was a correlation between the SpeedInfo data and an adjacent time stamp from Caltrans observation. This could account for any accuracy discrepancy due to the SpeedInfo sensor and Caltrans loop station being physically separated. However, there were no noticeable changes in the comparison.

We also further considered the speed ranges in different buckets as noted in Note 1 above. The larger the speed range in each bucket, the more likely the SpeedInfo measurements would match Caltrans loop data.. This means that if an end user has only a few buckets that they are interested (i.e., 0-20 mph, 20-50 mph, and 50+), then SpeedInfo sensors could be used along side Caltrans loop data..

Reliability

1. Was poor weather encountered during the evaluation? ☐ YES ☒ NO
2. If so, describe the type of weather and the effect, if any, on the system's range, accuracy and communications capabilities:_____
3. Can Caltrans maintain and/or install the device? ☒ YES ☐ NO

   Likely. Vendor claims that staff can be trained for installation within 30 minutes. Installation equipment should be readily available to Caltrans maintenance staff.

Productivity

1. Does the SpeedInfo data feed integrate with the 511 network? ☒ YES ☐ NO

   The integration between the SpeedInfo server and 511 was completed in approximately two weeks.

2. Does it improve 511's ability to calculate driving times? ☒ YES ☐ NO

   It provides an additional data source for calculating driving times and is a quick solution in areas where existing detection does not exist.

3. Can the device provide additional information such as density, volume, lane information, or minimum and maximum speeds? (circle any that apply or describe below)

   The equipment has only been tested for measuring speeds but future considerations could be expanded to include this type of data according to the Vendor.

4. Does the lack of any of the above prevent the data from providing a benefit to the Caltrans ATMS?

   Not necessarily. Some of the benefits could be lower costs in installation and maintenance and a quick solution to gathering speed data.

5. How do these performance measures relate to Caltrans' 9 Performance Measures?

   Caltrans' performance measures are used to assess the operations of multi-modal transportation systems in order to create a more accountable framework for decision making. The following table relates the project performance measures against the Caltrans performance measures.

	Caltrans 9 Performance Measures								
	Mobility/Accessibility/ Reliability	Productivity	System Preservation	Safety	Environmental Quality	Coordinated Transportation and Land Use	Economic Development	Return on Investment	Equity
Outputs Measured									
Accuracy	✓								
Cost	✓		✓					✓	
Reliability	✓								
Productivity	✓	✓					✓	✓	

4.3 Performance Factors

Interoperability and compatibility

SpeedInfo data feed is capable of integrating with 511 network very quickly. However, SpeedInfo does not provide volume, occupancy, and density data that are available with loop stations.

According to the Vendor, several considerations are taken into account when determining a sensor installation site. The main considerations are orienting the sensor to adequately capture specific traffic flow patterns; and have acceptable cellular signal levels 30 feet in the air. Proper solar panel orientation and exposure is also important, with the solar panel typically facing the south side sun.

The Vendor claims that the sensors would be expected to cover 750' to 1200' down the freeway considering California's typical infrastructure and roadway geometry. According to information provided by the Vendor, the distance between the sensor and the roadway measurement area for Bay area installations is typically between 400 to 600 feet. (There may be one or two locations in the Bay Area where this distance is 1500 feet on Interstate 280.) The distance between the sensor and the roadway measurement area is 750 feet for the evaluation location. These distances were not verified as part of this evaluation.

Most of the observed sensors in the San Francisco Bay Area are installed close to the freeway, typically on an existing Caltrans pole. According to the Vendor, if the sensor is located more than 150' from the fog line of the freeway, a cosine angle correction is required based on the width of the freeway and the pole location offset from the freeway.

According to the Vendor, a single server can accommodate up to 5000 sensors. The Vendor recommends that the density of sensors should be 1 per mile in urban settings, but 2-5 miles spacing is sufficient in rural or non-metropolitan areas.

The system is capable of on-the-air software installation/upgrades without being physically at the location. With an I/O port available on the device, additional components (such as cameras) can be connected using the same communication lines.

Safety

This device does not have a direct safety performance function. However, the sensors can relay changes in speed relatively quickly compared to other sources. This could give an advance indication of a potential incident that could be investigated further.

Staffing and Training

Vendor claims that maintenance is relatively low because the units are constructed to withstand the elements. However, a regular maintenance program should be considered to ensure that the devices are continuing to provide useful data. This effort is less time and cost than maintaining a loop station.

Once the data path is initially configured, there is no Caltrans or MTC staff involvement required.

Cost

See previous section for estimates of installation and maintenance costs. Other non-intrusive detection such as microwave or acoustical would have similar costs as a SpeedInfo sensor installation.

As the number of sensor deployments increase, the costs of installation, maintenance, and communication per sensor increase at a linear rate since each installation is independent from others. If multiple installations are done in a single field visit, there may be some savings in installation time.

5. Evaluation Methodology

How were the performance measures described above evaluated?

The SpeedInfo data feed was compared with Caltrans loop data at the locations, dates, and times as mentioned in the previous sections. The comparison was made by varying the location (two locations), time of day (different traffic speeds and densities), and the day of the month (weather).

Subsequently, GPS data was collected to establish a ground truth to compare the data sources.

- **The following information was obtained from the Vendor via telephone interviews and email:**
  - ***Installation requirements***
  - ***Maintenance requirements***
  - ***Speed sensor capabilities***
  - ***Cost requirements***
  - ***System restrictions***
- **Sample Sizes:**
  - ***Number of speed comparison readings taken: Two consecutive days of data from 7 AM to 6 PM with readings every 30 seconds.***
  - ***Number of locations analyzed in speed accuracy evaluation: Two***

6. Evaluation Results

The following figures illustrate the results of the two evaluations (direct comparison of SpeedInfo data and Caltrans loop data; comparison with GPS-based test runs. The results have already been discussed in the previous sections.

Figure 1 and **Figure 2** illustrate the comparison between Caltrans loop data and SpeedInfo Data for I-80 westbound at Gilman Street on two consecutive weekdays in December 2005 from 7 AM – 6 PM.

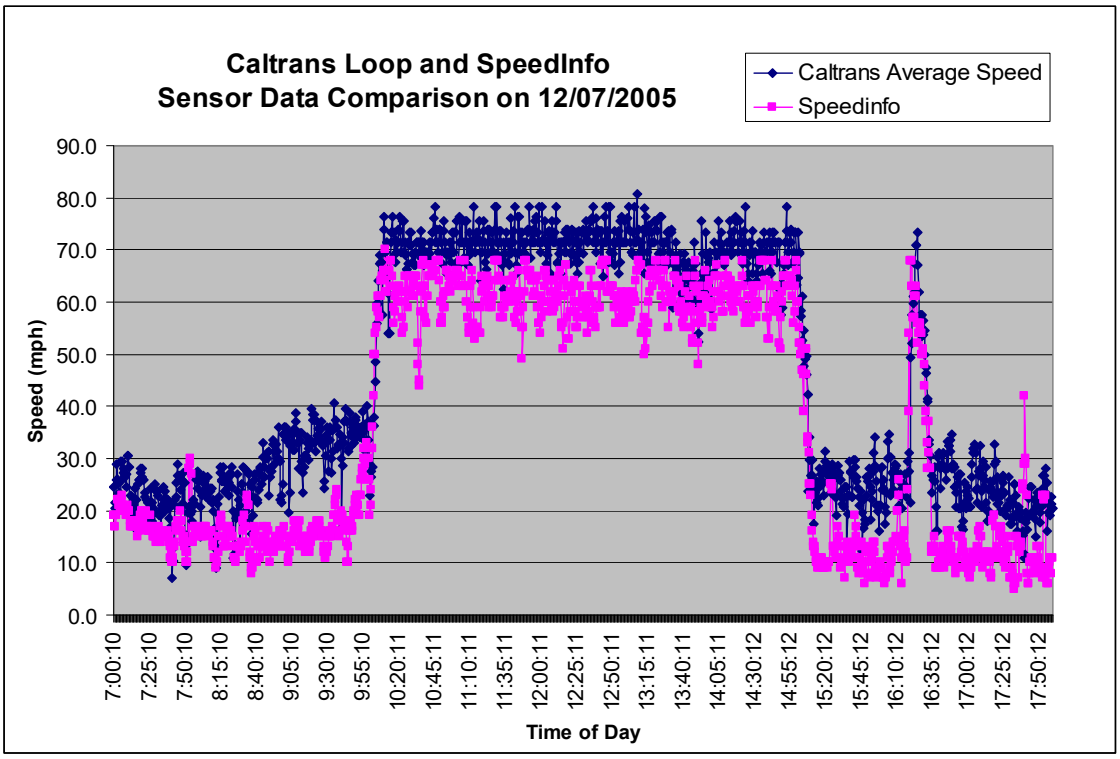

Figure 1: Speed Data Comparison on 12/07/2005 on I-80 westbound

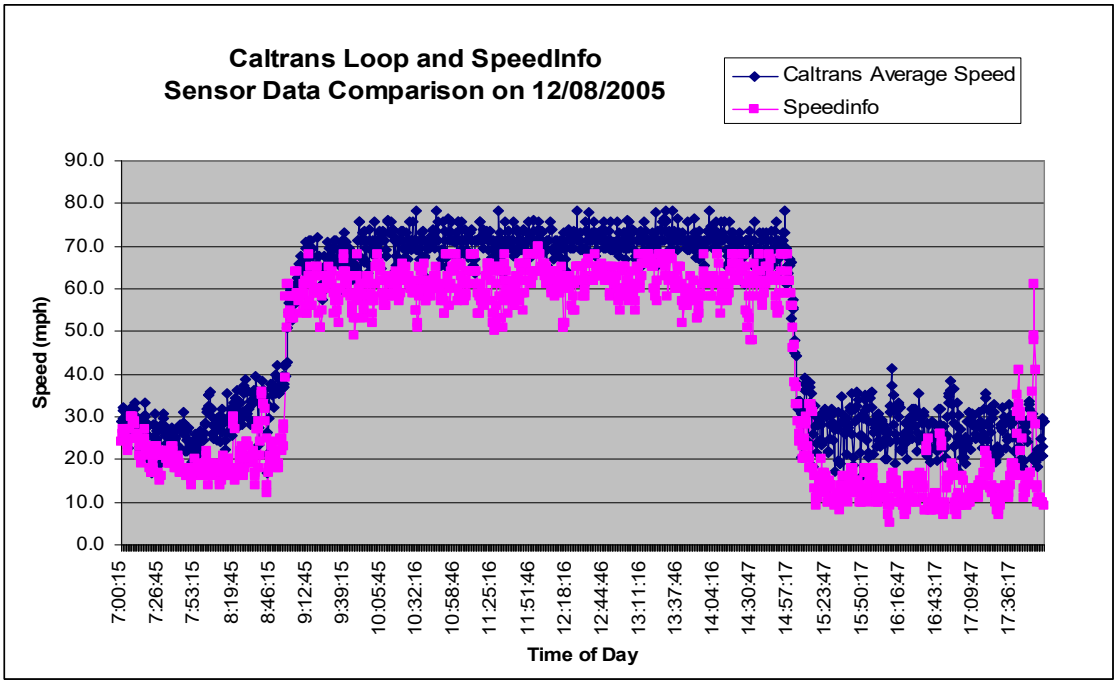

Figure 2: Speed Data Comparison on 12/08/2005 on I-80 westbound

Figure 3 and **Figure 4** illustrate the comparison between Caltrans loop data and SpeedInfo Data for I-80 eastbound at Gilman Street on two consecutive weekdays in December 2005 from 7 AM – 6 PM.

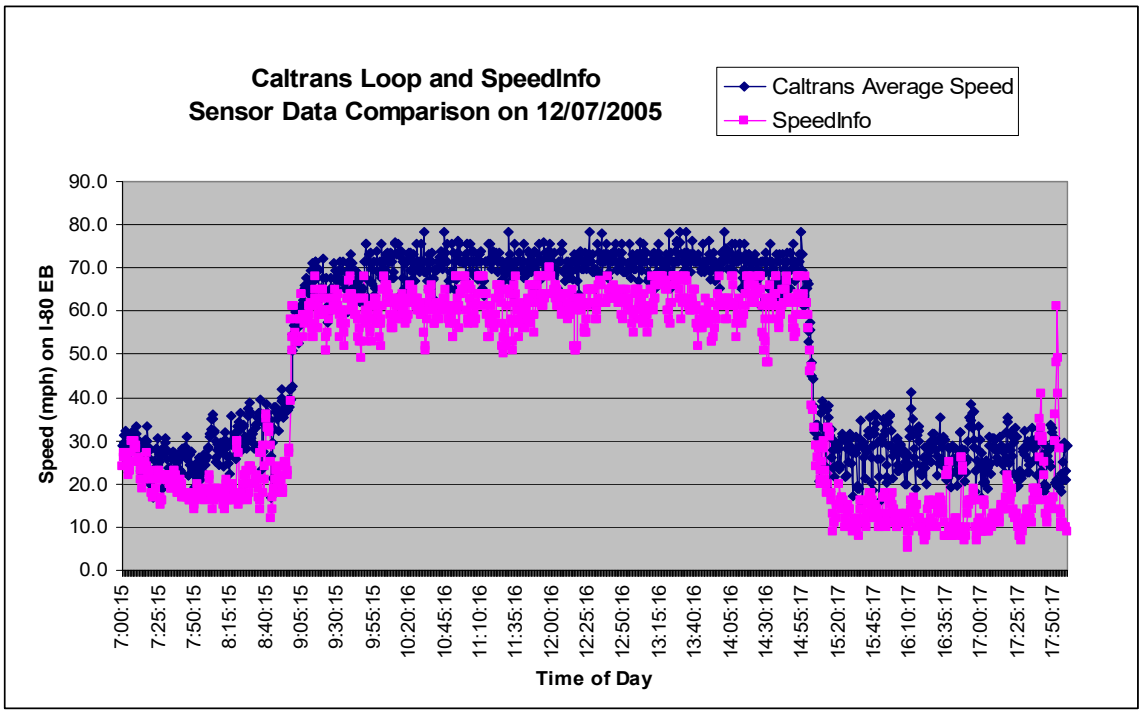

Figure 3: Speed Data Comparison on 12/07/2005 on I-80 eastbound

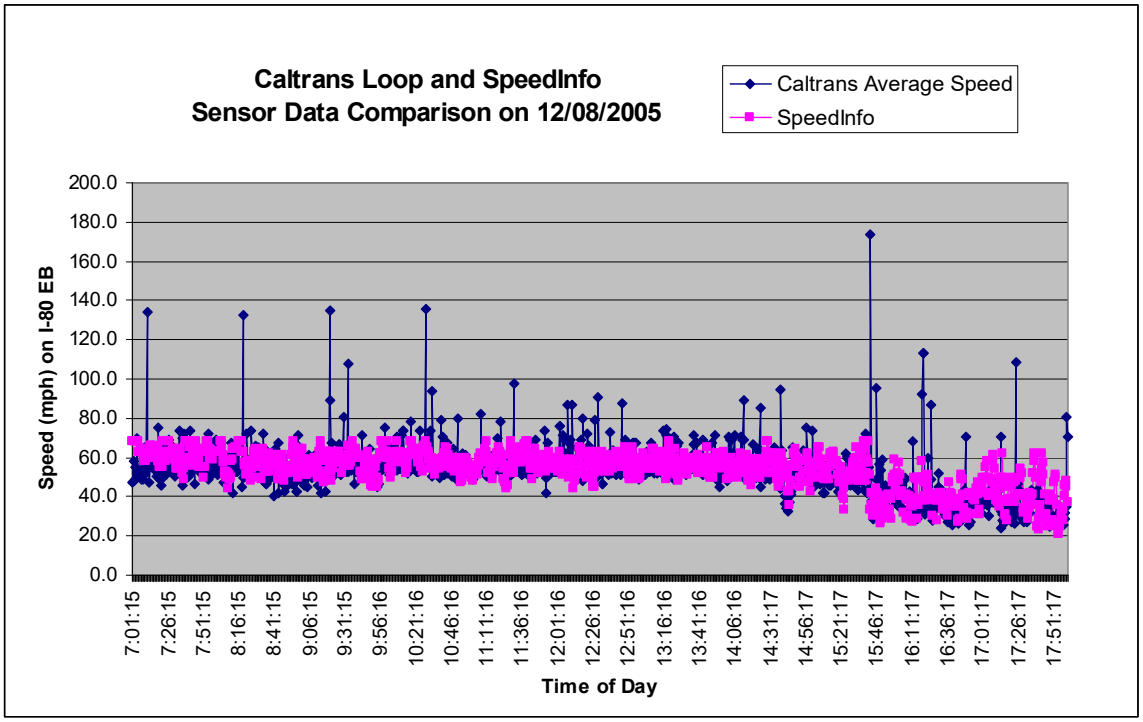

Figure 4: Speed Data Comparison on 12/08/2005 on I-80 eastbound

Figure 5 illustrates the speed difference between the GPS-based test runs and Caltrans loop data and SpeedInfo Data for I-80 westbound at Gilman Street on January 18th 2006 for AM, Mid-day, and PM peak periods. Two runs were performed for each peak period.

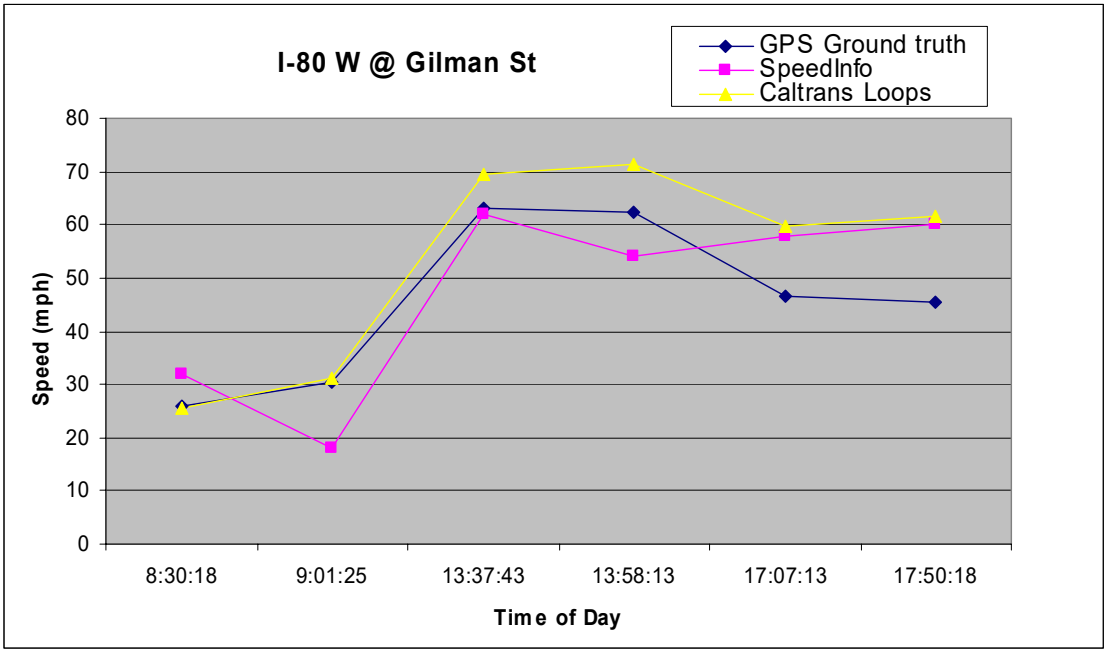

Figure 5: Speed Data Comparison with GPS-based test runs on I-80 westbound

Figure 6 illustrates the percentage difference in speeds between the GPS-based test runs and Caltrans loop data and SpeedInfo Data for I-80 westbound at Gilman Street on January 18th 2006 for AM, Mid-day, and PM peak periods. Two runs were performed for each peak period.

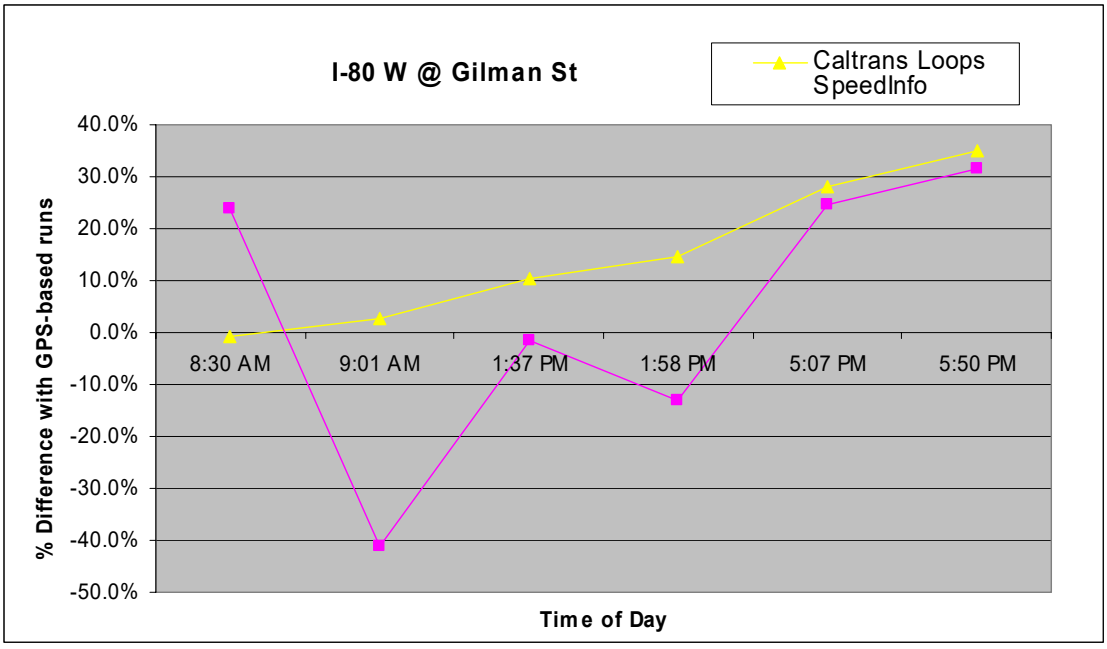

Figure 6: Speed Data Comparison in % with GPS-based test runs on I-80 westbound

Figure 7 and **Figure 8** illustrate similar figures based on GPS test runs for I-80 eastbound at Gilman Street. Two runs were performed for each of the three peak periods.

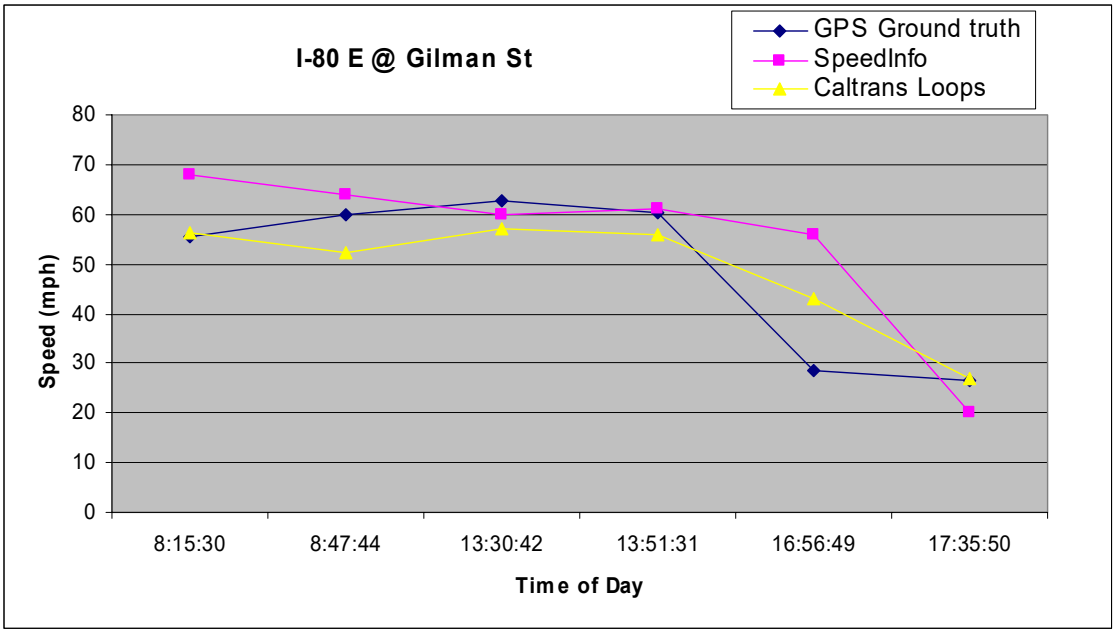

Figure 7: Speed Data Comparison with GPS-based test runs on I-80 eastbound

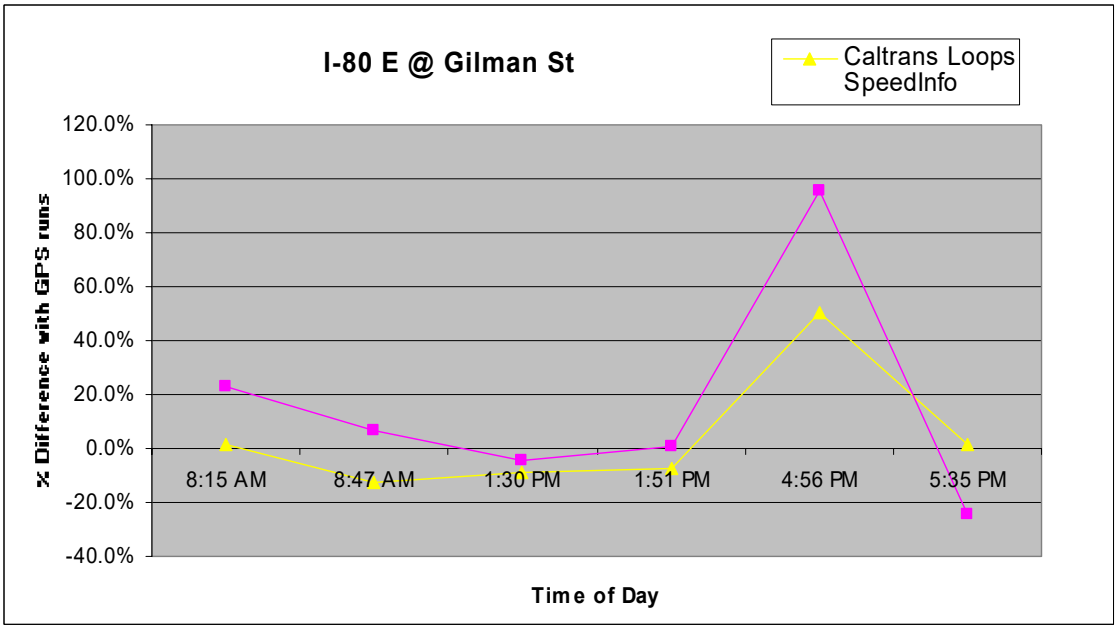

Figure 8: Speed Data Comparison in % with GPS-based test runs on I-80 eastbound

In the figures presented in this section, it shows that there is an overall correlation between the SpeedInfo sensor data and the Caltrans loop data. The SpeedInfo data is nearly always below the Caltrans data so this could be a simple configuration in the sensor algorithms. It was apparent, though, that as the freeway speeds decreased, the SpeedInfo sensor data fell further below the Caltrans loop data.

When comparing the SpeedInfo sensor data and Caltrans loop data to the GPS ground truth data, it appeared that the eastbound SpeedInfo data correlated closer to the ground truth data than the correlation of Caltrans data. However, in the westbound direction, the Caltrans data correlated to the ground truth much better that the SpeedInfo sensor data.

7. Vendor comments

The Vendor provided some additional comments on the evaluation. These comments are summarized below:

- There are many different ways to measure speed on a roadway and some variability would be expected between the results of each approach. Differences in reported speeds can be attributed to variations in measurement and testing methodology as well as differences in sample data interpretation.
- SpeedInfo's Doppler radar system is accurate to within 1/10th of a mph and each unit is tested and verified to meet this performance requirement prior to installation. Distance and angles between the sensor and the measurement area do not necessarily account for the difference between SpeedInfo results and Caltrans results.
- Other possible sources of discrepancy between the SpeedInfo data and other sources of data may include the following:
    - Caltrans loops are not in the same location as SpeedInfo measurement area. The distance between the Caltrans loop and the SpeedInfo sensor within the sample area could be a major contributor to the observed differences. Data averaging algorithms, HOV lanes, and specific traffic flow patterns in the area contribute to the differences.
    - At low speeds, measurement errors of a few mph translate into large percentage discrepancies.
- SpeedInfo continues to work with Caltrans as they prepare to evaluate several sensor technologies. Creating a test set-up that will allow data correlation and reduce the natural variations when using different sensors (with different trap zones and data processing algorithms) has been difficult. This effort is on-going.
- A single SpeedInfo sensor provides coverage for both sides of the roadway and there are only slight differences between near side and far side performance; none of them impact accuracy.

8. Recommendations

The following table represents pros and cons that were observed and noted during this evaluation. The reader or end user should consider this information against the specific application to determine if this product can provide the desired solution.

PROS	CONS
Provides ability to access speed data at locations without data infrastructure in place.	Currently provides only an average speed per sample size. Devices do not provide volume, occupancy and density data provided by loops.
Low power requirements and runs on solar power.	Does not break down data per travel lane.
Ease of installation and configuration into an existing SpeedInfo system.	Crystal clock device failure and other failures cannot be predicted. (Issue appears to have been resolved.)
Uses proven Doppler technology.	
Installation cost is a fraction of the cost to install inductive loop stations on both sides of the road.	
Flexibility in adjusting the location of speed measurement area.	
Easy data access for public via website.	

Appendix A
Vendor Specification Sheet

SpeedInfo
less traffic, more time

DVSS-100
Doppler Vehicle Speed Sensor

Description

SpeedInfo's DVSS-100 Doppler Vehicle Speed Sensor is a fully self contained, roadside mounted, vehicle speed measurement sensor. This non-intrusive, high performance speed sensor shatters existing sensor performance and cost points. In addition to low unit cost, the sensor is extremely robust and will perform maintenance free for years. The sensor is battery powered, solar charged, and mounts quickly on existing poles or overpasses.

The DVSS-100 uses a 24.125 GHz Doppler microwave transceiver coupled to a Digital Signal Processor, to measure and calculate vehicle speed. The DVSS-100 is capable of determining average or composite vehicle speed for a multiple lane freeway or highway. Speed information is backhauled to SpeedInfo's data server over a GSM cellular data link.

Specifications

Coverage

- Range up to 1800 ft
- Installs on existing infrastructure – no new poles; mounts on virtually anything
- 20 minute installation and calibration time; 10 minute replacement time
- Configurable coverage areas to suit specific installation requirements

Communication

- Real-Time Traffic Information reporting
- GPRS wireless modem data-backhaul (850/1900 MHz); additional frequencies available
- Adaptive traffic speed reporting (Variable reporting schedules based on congestion level)
- Full duplex/Bi-directional

Measurement

- Bi-directional traffic data collection
- Configurable data acquisition/sample rate
- Average speed accuracy within +/- 1mph
- 1/10th mph for single vehicle in field of view
- HOV-lane speed measurements

Mechanical

- Enclosure
  - Anodized aluminum extrusion
  - Bright White Powder Coat
  - 14.3” Length (.36m)
  - 4” Tube diameter (.10m)
- Weight
  - 13 Lbs (5.9kg) w/o mounting bracket and solar panel
  - 16 Lbs (7.3kg) with mounting bracket and 5W solar panel

FCC

- Part 15 certified

Environmental

- Operating temperature
  - -20°C to +70°C
- Relative Humidity
  - 0% to 100%
- Shock and vibration
  - Shock of 5 g 10mSec half sine wave
  - Vibration of 2g up to 200Hz

System Power

- Battery and charge system
  - 12V 5 Amp hour sealed tin/lead acid battery
  - 17 day operation w/o re-charge (No sunlight condition)
  - 8-10 year battery life
- Solar panel charging system
  - 5 or 10 Watt solar panel
  - Approximately 1 sq. ft. in total area
  - Battery/charge alarms

Reliability

- MTBF greater than 60,000 hours

Sensor Platform/Modularity

- Temperature and fog sensors
- Visual sensors for incident verification
- Vehicle counts

Serviceability

- On board diagnostics/self test
- Over-the-air software updates (No service calls)

Contact Information:

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Specifications subject to change

Appendix B
Caltrans and SpeedInfo Speed Comparison

ID	Period Ending		Caltrans Average Speed	SpeedInfo	ID	Time	Speed	Difference	+-5%	+-7%	+-10%	+-20%
L4-W-33-080-00664	12/7/2005	7:00:10	24.7	7649	12/7/2005	7:00:12	19	-23.0%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:00:40	21.7	7649	12/7/2005	7:00:42	17	-21.5%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:01:10	20.3	7649	12/7/2005	7:01:12	17	-16.4%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:01:40	26.0	7649	12/7/2005	7:01:42	19	-26.9%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:02:10	29.0	7649	12/7/2005	7:02:12	19	-34.5%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:02:40	26.0	7649	12/7/2005	7:02:43	22	-15.4%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:03:10	25.0	7649	12/7/2005	7:03:13	22	-12.0%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:03:40	23.3	7649	12/7/2005	7:03:42	21	-10.0%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:04:10	21.7	7649	12/7/2005	7:04:12	21	-3.1%	TRUE	TRUE	TRUE	TRUE
L4-W-33-080-00664	12/7/2005	7:04:40	21.7	7649	12/7/2005	7:04:42	20	-7.7%	FALSE	FALSE	TRUE	TRUE
L4-W-33-080-00664	12/7/2005	7:05:10	29.3	7649	12/7/2005	7:05:12	22	-25.0%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:05:40	29.3	7649	12/7/2005	7:05:42	22	-25.0%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:06:10	26.0	7649	12/7/2005	7:06:12	23	-11.5%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:06:40	27.3	7649	12/7/2005	7:06:42	21	-23.2%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:07:10	28.0	7649	12/7/2005	7:07:12	20	-28.6%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:07:40	26.3	7649	12/7/2005	7:07:43	20	-24.1%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:08:10	27.0	7649	12/7/2005	7:08:13	20	-25.9%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:08:40	24.7	7649	12/7/2005	7:08:42	20	-18.9%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:09:10	27.0	7649	12/7/2005	7:09:12	19	-29.6%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:09:40	30.7	7649	12/7/2005	7:09:42	21	-31.5%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:10:10	30.7	7649	12/7/2005	7:10:12	20	-34.8%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:10:40	28.3	7649	12/7/2005	7:10:42	20	-29.4%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:11:10	19.7	7649	12/7/2005	7:11:12	20	1.7%	TRUE	TRUE	TRUE	TRUE
L4-W-33-080-00664	12/7/2005	7:11:40	19.7	7649	12/7/2005	7:11:42	18	-8.5%	FALSE	FALSE	TRUE	TRUE
L4-W-33-080-00664	12/7/2005	7:12:10	23.0	7649	12/7/2005	7:12:12	17	-26.1%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:12:40	22.7	7649	12/7/2005	7:12:43	17	-25.0%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:13:10	19.3	7649	12/7/2005	7:13:13	17	-12.1%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:13:40	21.3	7649	12/7/2005	7:13:42	18	-15.6%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:14:10	17.0	7649	12/7/2005	7:14:12	17		TRUE	TRUE	TRUE	TRUE
L4-W-33-080-00664	12/7/2005	7:14:40	19.0	7649	12/7/2005	7:14:42	17	-10.5%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:15:10	24.3	7649	12/7/2005	7:15:12	18	-26.0%	FALSE	FALSE	FALSE	FALSE
L4-W-33-080-00664	12/7/2005	7:15:40	22.0	7649	12/7/2005	7:15:42	18	-18.2%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:16:10	16.3	7649	12/7/2005	7:16:12	18	10.2%	FALSE	FALSE	FALSE	TRUE
L4-W-33-080-00664	12/7/2005	7:16:40	18.7	7649	12/7/2005	7:16:42	17	-8.9%	FALSE	FALSE	TRUE	TRUE

Appendix C
"Ground Truth" Speed Comparison

Caltrans ID	Period Ending	Caltrans Average Speed	Speed Info ID	Time	Speed		GPS Time	GPS Speed	Caltrans Difference	SpeedInfo Difference
L4-E-33-080-00664	1/18/2006 08:15:22 AM	37.5	7650	1/18/2006 8:15	61					
L4-E-33-080-00664	1/18/2006 08:15:52 AM	**56.3**	7650	1/18/2006 8:15	**68**		8:15:30	55.40146	1.53%	22.74%
L4-E-33-080-00664	1/18/2006 08:16:22 AM	57.5	7650	1/18/2006 8:16	68					
L4-E-33-080-00664	1/18/2006 08:16:52 AM	51.0	7650	1/18/2006 8:16	68					
L4-E-33-080-00664	1/18/2006 08:47:22 AM	**52.3**	7650	1/18/2006 8:46	55					
L4-E-33-080-00664	1/18/2006 08:47:52 AM	35.8	7650	1/18/2006 8:47	59					
L4-E-33-080-00664	1/18/2006 08:48:22 AM	35.8	7650	1/18/2006 8:47	**64**		8:47:44	59.87533	-12.74%	6.89%
L4-E-33-080-00664	1/18/2006 08:48:52 AM	44.3	7650	1/18/2006 8:48	68					
L4-E-33-080-00664	1/18/2006 08:49:22 AM	53.3	7650	1/18/2006 8:48	63					
L4-E-33-080-00664	1/18/2006 01:32:23 PM	53.8	7650	1/18/2006 13:29	50					
L4-E-33-080-00664	1/18/2006 01:32:53 PM	52.0	7650	1/18/2006 13:30	57					
L4-E-33-080-00664	1/18/2006 01:33:23 PM	53.0	7650	1/18/2006 13:30	**60**		13:30:42	62.63422	-8.60%	-4.21%
L4-E-33-080-00664	1/18/2006 01:33:53 PM	50.8	7650	1/18/2006 13:31	61					
L4-E-33-080-00664	1/18/2006 01:34:23 PM	50.8	7650	1/18/2006 13:31	56					
L4-E-33-080-00664	1/18/2006 01:52:53 PM	53.0	7650	1/18/2006 13:50	61					
L4-E-33-080-00664	1/18/2006 01:53:23 PM	55.3	7650	1/18/2006 13:50	61					
L4-E-33-080-00664	1/18/2006 01:53:53 PM	53.3	7650	1/18/2006 13:51	**61**		13:51:31	60.39728	-7.28%	1.00%
L4-E-33-080-00664	1/18/2006 01:54:23 PM	54.3	7650	1/18/2006 13:51	55					
L4-E-33-080-00664	1/18/2006 01:54:53 PM	53.5	7650	1/18/2006 13:52	50					
L4-E-33-080-00664	1/18/2006 04:59:54 PM	41.0	7650	1/18/2006 16:55	52					
L4-E-33-080-00664	1/18/2006 05:00:24 PM	34.0	7650	1/18/2006 16:56	56					
L4-E-33-080-00664	1/18/2006 05:00:54 PM	35.5	7650	1/18/2006 16:56	**56**		16:56:49	28.63278	50.18%	95.58%
L4-E-33-080-00664	1/18/2006 05:01:24 PM	35.5	7650	1/18/2006 16:57	47					
L4-E-33-080-00664	1/18/2006 05:01:54 PM	36.0	7650	1/18/2006 16:57	40					
L4-E-33-080-00664	1/18/2006 05:38:54 PM	37.0	7650	1/18/2006 17:34	22					
L4-E-33-080-00664	1/18/2006 05:39:24 PM	28.0	7650	1/18/2006 17:35	18					
L4-E-33-080-00664	1/18/2006 05:39:54 PM	31.5	7650	1/18/2006 17:35	**20**		17:35:50	26.39585	1.34%	-24.23%
L4-E-33-080-00664	1/18/2006 05:40:24 PM	30.5	7650	1/18/2006 17:36	22					
L4-E-33-080-00664	1/18/2006 05:40:54 PM	24.5	7650	1/18/2006 17:36	21					