STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT DOCUMENTATION PAGE

TR0003 (REV 10/98)

1. REPORT NUMBER	2. GOVERNMENT ASSOCIATION NUMBER	3. RECIPIENT'S CATALOG NUMBER
CA 15-1919		

4. TITLE AND SUBTITLE

Phase III: Research and Development of an E85 Alternative Fuel Fleet Monitoring System

5. REPORT DATE

February 2015

6. PERFORMING ORGANIZATION CODE

UC Riverside

7. AUTHOR

Michael Todd and Matthew Barth

8. PERFORMING ORGANIZATION REPORT NO.

Final Report 18983

9. PERFORMING ORGANIZATION NAME AND ADDRESS

UC Riverside
CE-CERT
1084 Columbia Ave.
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10. WORK UNIT NUMBER

TSR

11. CONTRACT OR GRANT NUMBER

65A0382

12. SPONSORING AGENCY AND ADDRESS

Caltrans
Division of Research, Innovation and System Information
P.O. Box 942873
Sacramento, CA 94273-0001

13. TYPE OF REPORT AND PERIOD COVERED

Demonstration project summary and results from June 2010 through March 2014

14. SPONSORING AGENCY CODE

Caltrans

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This study has allowed for development, deployment, and evaluation of a telematics architecture for E85 fleet monitoring and fuel use across four Caltrans Districts. This expanded study integrated both cellular and Wi-Fi data reporting at each of the four District locations for comparison and analysis. The collected vehicle data identifies vehicle activity trends which impact fuel use and refueling activities. This expanded deployment has provided and demonstrated the feasibility of collecting combined fleet operations and refueling activity in a single centralized system. This project has developed, implemented, and evaluated a system that can monitor alternative fuel usage in the Caltrans fleet, and provide a means for managers and supervisors to access these data in a meaningful way. The developed system includes on-board monitoring hardware that has telematics capabilities of sending this information to a system server that is readily accessed via the Internet.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Fleet Fuel Monitoring, GPS, Telematics, Vehicle Activity, E85, Ethanol, Flex Fuel, Trip Reporting, Cellular, Wi-Fi, 80211	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. SECURITY CLASSIFICATION *(of this report)*	20. NUMBER OF PAGES	21. COST OF REPORT CHARGED
Unclassified	74	

DISCLAIMER STATEMENT

UCR | College of Engineering- Center for Environmental Research & Technology

Phase III
Research and Development of an E85 Alternative Fuel Fleet Monitoring System

Contract 65A0382

FINAL REPORT

Prepared for:

Caltrans

Division of Research, Innovation and System Information

By:

College of Engineering – Center for Environmental Research and Technology

University of California at Riverside

February 2015

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ACKNOWLEDGMENT

The authors express appreciation to the following associates who contributed much to the success of the project and the furtherance of E85 alternative fuel vehicle use. We very much appreciate the financial support of Caltrans Division of Research, Innovation and System Information throughout the project. The Task Advisory Group members listed below provided their support, effort, and guidance in the success of this project and research.

Task Advisory Group

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EXECUTIVE SUMMARY

Over time, the California Department of Transportation (Caltrans) has invested in a variety of alternative fueled vehicles as part of its in-use vehicle fleet. However, it has been very difficult to detail individual vehicle fuel use characteristics, especially when the vehicles have bi-fuel capability (i.e., can run on gasoline or ethanol, gasoline or propane, gasoline or CNG, etc.). This project has deployed a telematics system comprising of on-board vehicle data collecting units from several different suppliers and manufactures. The telematics hardware integrate vehicle location data (telemetry) with vehicle activity data, such as, speed, key on, key off, and fuel use. The installations have been distributed across four districts (D4, D7, D8, and D11) to facilitate an evaluation across different regions of the state. The telematics data received from the multiple vendor units have been integrated into a centralized server system that can monitor alternative fuel usage in the Caltrans fleet, and provide a means for management to access these data in a meaningful way. The developed system is readily accessed via the Internet and provides access for reviewing fuel use, trip data, and vehicle locations.

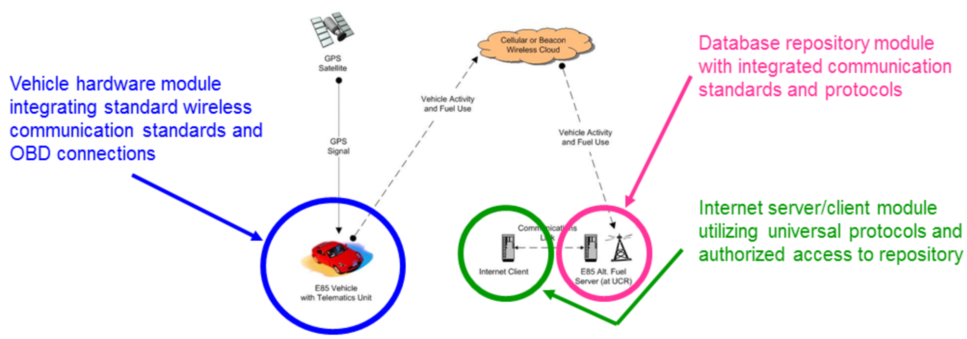


Figure ES.1. E85 alt-fuel system monitoring architecture with combined cellular and Wi-Fi.

Caltrans, as part of its alternative fueled vehicle program, has been increasing its ethanol (E85) compatible vehicle fleet size. Monitoring E85 fuel usage to help quantify fuel usage patterns within the vehicle fleet has previously proven to be a challenge. Traditional methods of matching E85 refueling records with vehicle identity have provided little insight with regards to vehicle activity of specific vehicles. The deployment of vendor telematics units within this project allows for evaluation and comparison between vendors. The telematics system is shown in Figure ES.1 and consists of an onboard telematics device which collects real time sensor parameters from the vehicles OBD-II (On Board Diagnostics) port. Once a trip has started the system logs the real-time engine data along with the vehicles GPS position. Upon conclusion of a trip the information is compiled and transferred to an Alt Fuel computer server via a cellular connection or Wi-Fi transceiver located within motorpool parking garages at District offices. The associated system components include:

- GPS vehicle positioning utilizing satellite broadcasts;
- Vehicle telematic units interfaced with the vehicle OBD-II data bus;
- Cellular or Wi-Fi data communications for transmission of vehicle activity and fuel consumption data;
- Data repository and server for receiving and storing transmitted data; and

- Web-based user interface for reviewing previous vehicle activity and fuel consumption data.

The system architecture was specifically designed and modified to integrate fuel composition data and vehicle activity (location, miles travelled, speed etc.) from multiple vendor units. The system base architecture was initially developed in a previous pilot deployment for ten vehicles and expanded in this current project to include 100 vehicles dispersed among four districts. This integrated project has collected significant data over a period of nearly two years consisting of:

- 37,309 trips with second-by-second GPS location;

- 588,141 miles of OBD-II monitoring;

- 29,837 gallons of fuel consumed with refueling event locations; and,

- 19.7 mpg average fuel economy.

The web based user interface was improved within this program to integrate all four deployment districts utilizing on-board telematics from numerous selected vendors. Figure ES.2 shows an example of a specific trip completed during the program with a refueling event. This type of user interface has allowed for determination of vehicle activity relative to refueling. E85 fuel use trends have been evaluated relative to vehicle activity and trip reporting. The analysis has shown that significant trends exist according to vehicle model and operating location.

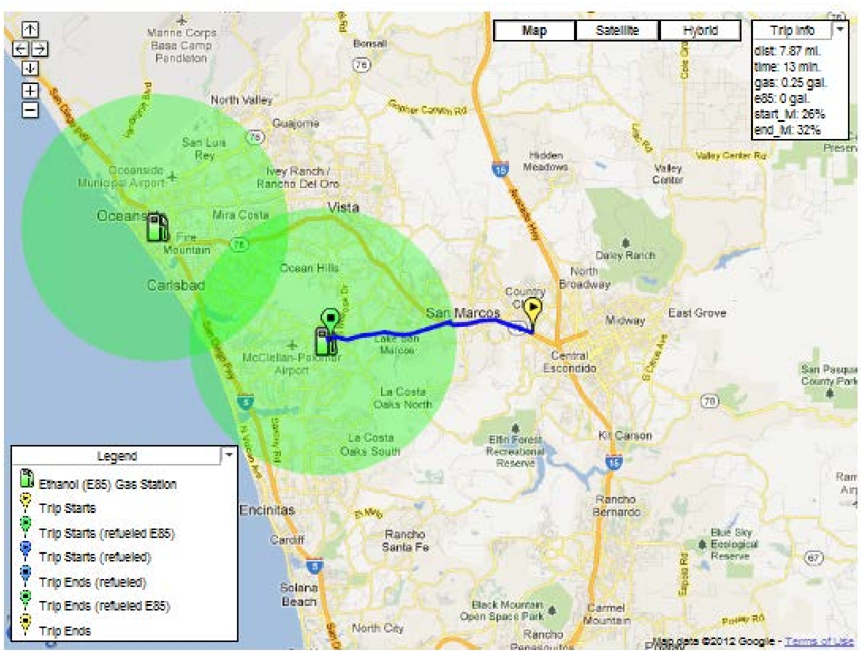


Figure ES.2. Caltrans E85 user interface mapping function.

This study has allowed for development, deployment, and evaluation of a telematics architecture for E85 fleet monitoring and fuel use across four Districts. This expanded study integrated both cellular and Wi-Fi data reporting at each of the four District locations for comparison and analysis. The collected vehicle data identifies vehicle activity trends which impact fuel use and refueling activities. This expanded deployment has provided and demonstrated the feasibility of collecting combined fleet operations and refueling activity in a single centralized system.

Numerous conclusions have been drawn from the technology implementation, expanded deployment, wireless communications, vendor options, data analysis, and results presented in this report. The extensive analysis of vehicle activity and fuel use has provided key conclusions and areas of interest which include:

- 85 percent is a maximum threshold of ethanol for E85 with actual observed percentages being closer to 75 percent;
- Cellular communications are an effective and reliable means of wireless real time data transfer, but with associated data costs;
- Wi-Fi communications are a cost effective and reliable method of post trip data transfer when vehicles return to a “home base”;
- The OBD-II connector is the ideal interface to connect fuel monitoring on-board hardware;
- Few vendors supply OBD integrated on board telematics capable of Wi-Fi communications that can be adapted to fuel monitoring applications;
- Numerous vendors supply OBD integrated on board telematics with cellular data transfer;
- Data originating from diverse multi-vendor supplied on board data units can be seamlessly integrated into a single centralized database, and;
- Web client applications have been implemented to review vehicle activity and fuel use independent of telematics supplier or data communication method.

These implementation, demonstration, and analysis have provided a foundation for a future deployment of a commercial scale system. The future system should build upon the strengths of the expanded deployment program while adding attributes. A key attribute is the modular open architecture which allows flexibility in communication technology (cellular or Wi-Fi) aggregated within a single database. This architecture creates a framework for future advanced fuel/energy monitoring and affiliated Intelligent Transportation System (ITS) applications. Additionally, improved on-board functionality could assist drivers in knowing current fuel composition, E85 refueling locations, and fuel savings. Finally, enhanced web-based applications can assist staff, managers, and fleet operators in characterizing vehicle activity and quantifying fuel use.

1. INTRODUCTION

Caltrans has successfully deployed alternative fuel vehicles throughout the state District locations for department operations and motorpool utilization. By using alternative fueled vehicles that run on ethanol, compressed natural gas (CNG), propane, or bio-diesel, there should be a quantitative improvement in CO_2 emissions, better fuel economy, and general support for energy independence. However, it has been very difficult to determine the amount of alternative fuels these vehicles are actually using, especially when the vehicles have bi-fuel capabilities (i.e., can run on gasoline or ethanol, gasoline or propane, gasoline or CNG, etc.). A rough idea of fuel consumption can be determined through general fuel sales data, however these data are somewhat limited.

This project has developed, implemented, and evaluated a system that can monitor alternative fuel usage in the Caltrans fleet, and provide a means for managers and supervisors to access these data in a meaningful way. The developed system includes on-board monitoring hardware that has telematics capabilities of sending this information to a system server that is readily accessed via the Internet. This prototype system has been implemented and evaluated as part of the expanded pilot study. Caltrans' Division of Equipment has recently purchased General Motors Ethanol 85 (E85) vehicles and provided 100 vehicles as part of the expanded pilot study.

This project has been carried out in several phases: In Phase I, a prototype system was developed consisting of ten instrumented vehicles. Five of these vehicles were deployed in Caltrans District 11 and five in Caltrans District 3. The system server is located in Riverside California, which can be accessed 24 hours a day via the Internet. After developing the on-board hardware and system server, the hardware was placed in the vehicles with subsequent data collection occurring over six months. After completion of Phase I, Phase II consisted of a comprehensive evaluation followed by the development of a deployment plan for additional vehicles and system expansion.

The overall goals of Phase II were completed in 2010 and consisted of a final report describing the following:

1. Development, deployment and evaluation of a pilot system that can meet the needs of Caltrans to better manage their alternative fueled vehicle fleet;

2. Document the usage of alternative fuels (e.g., ethanol) in the alternative fueled vehicle fleet;

3. Provide supervisors and managers with a web-based means to manage their vehicle fleet that could potentially lead to drivers modifying their behavior to increase their use of alternative fuels; and,

4. Evaluation of system operation and creation of a deployment plan for system expansion and commercialization potential.

This current report summarizes the work completed since June of 2010 and is titled Phase III Research and Development of an E85 Alternative Fuel Monitoring. The Phase III research encompassed the expansion of the prototype system to four Caltrans districts and included select telematic vendor participation. The tasks completed for Phase III are detailed as follows:

Task 1: Convene TAG and Conduct Kickoff Meeting

A Technical Advisory Group (TAG) had already been created for this project during the initial two phases, consisting of personnel from the Caltrans Division of Equipment (DOE) and from the Division of Research, Innovation and System Information (DRISI). An initial kickoff meeting was held consisting of continuing TAG members and additional members pertaining to new District locations and new system architecture deployments.

Task 2: Quarterly Reporting and Final Report

Based on Caltrans' guidelines, quarterly reports were written and submitted by the research team, describing the work that has been carried out during the previous quarter and the planned research for the following quarter. University of California: Riverside (UCR) documented the protocols and communication standards evaluated and implemented during the project. UCR compiled the results achieved during the implementation, deployment, and demonstration period.

Task 3: Vehicle Telematics Enhancements

This task evaluated on-board vehicle electronics and expanded functionality with additional wireless and output options (e.g. WiFi, DSRC, GUI). When determined by the TAG, additional wireless technologies were integrated for reduced operating cost or improved system functionality. This included the integration of WiFi in centralized fleet locations (e.g. motor pool yard).

Task 4: Data Repository Hardware Improvements

The previous database hardware components and architecture were transitioned to a database hardware platform for compatibility with independently managed servers and support services. It is anticipated that the future database management will occur off-site and independent of UCR or Caltrans. This task allowed for the evaluation and implementation of hardware architectures suitable for system portability and expansion.

Task 5: Vehicle Telematics Evaluation

Each vehicle integrated within the system contained an on-board vehicle telematics unit which integrated with the OBD-II data bus. This task evaluated the expanded system and communication capabilities with non-proprietary protocols. The telematics units gathered trip related vehicle activity data and transmitted relevant data to the database repository utilizing non-proprietary protocols. Third party telematic providers employed independently developed hardware and software for their own telematics units. UCR provided the telematic providers with communication protocols and needed vehicle parameters.

Task 6: Data Repository Specification

The data repository module resides on the server(s) and received incoming vehicle activity data. This defined the protocols and communication messaging to allow for multi-vendor data receiving. Additionally, security and access protocols to limit communications only to authorized entities were specified. This task created data structures which were expandable and applicable to current and future ITS data applications. The database architecture developed in the first two phases was expanded and enhanced allowing for seamless communication with protocols developed in Task 5.

Task 7: User Interface Configuration

UCR implemented additional functionality on the server/client interface. UCR utilized input from the TAG on system configuration and added functionality. The interface utilized defined protocols for access to the data repository. The internet based client was further enhanced to detail E85 fuel use and relevant vehicle activity. This seventh task allowed for independent modular configuration of a user interface. Specific TCP/IP protocols were identified and documented to allow for data retrieval from the database repository.

Task 8: Deployment Plan Review

UCR and TAG members reviewed the details of the deployment plan with consideration to other complimentary systems within Caltrans, vendor participation, vehicle characteristics, fleet-wide implementation, and technology enhancements.

Task 9: Emissions Evaluation and Economic Incentives in Support of a Business Plan

UCR reviewed an emissions evaluation of the program fleet E85 fuel use. Additional economic incentives were explored for E85 fuel use monitoring, such as, navigational aids for E85 refueling locations determination. This task created supportive analysis that Caltrans can integrate with internal economic and operational data.

Task 10: Vendor Recruitment

UCR performed outreach to vendors to gain program participation. Participation from several vendors was achieved that equipped 75 additional vehicles with their hardware for demonstration purposes. This task led to a total of 75 vendor assigned vehicles being equipped. The vendors incurred the installation and hardware cost through the demonstration period. The vendors received program information and guidance relating to database communication and server connections to the repository.

Task 11: UCR Telematics Implementation

UCR provided hardware for 25 vehicles on several different models (including the previously equipped models). This hardware demonstrated the functionality expected from the vendor supplied telematics. Deployment of UCR installed telematics consisted of four District locations to serve as a comparison relative to vendor supplied units.

Task 12: System Operation

UCR oversaw the system operation, data collection, and server/client interface. The vendor equipped vehicles reported data to the UCR-implemented and UCR-monitored repository. Once the data was received from the third party vendor equipped-vehicles, UCR managed the data and representation of information to the client interface.

Task 13: Wi-Fi Review and Telematics Rental

This final task was extended with an amendment to compare Wi-Fi performance relative to cellular based telematics. The Wi-Fi option has additional transceiver installation at the District office motorpool vehicle parking locations allowing for batch data transmission. Additionally, some vendor units were rented for the project duration and returned at the project termination.

This report further details the results associated with these Phase III tasks. The project and task schedule is shown in Figure 1.1 with the final amendment dates shown in yellow. The total project duration is from July 2010 through March of 2014.

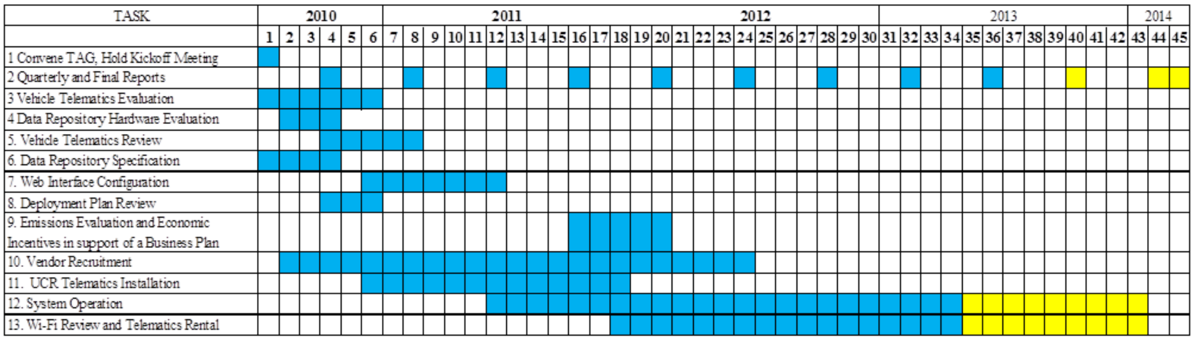


Figure 1.1. Phase III E85 Alternative Fuel Monitoring project schedule by task (amendment in yellow).

2. BACKGROUND

Caltrans has invested a significant amount of funding into alternative fueled vehicles, as well as the fuel they use. Currently there are hundreds of alternative fueled vehicles in the Caltrans fleet, ranging from ethanol (E85) vehicles to bi-fueled pickups. In order to better understand their alternative fuel consumption, a telematics-based system that can monitor fuel use, fuel mix, refueling locations and times has been implemented. This system can be expanded in the future to inform drivers of refueling opportunities to maximize the use of alternative fuels.

2.1. Vehicle Activity Telematics Programs at CE-CERT

UC Riverside's Center for Environmental Research and Technology (CE-CERT) has been developing telematics system designs for general vehicle activity research programs for a number of years. From 1999 – 2007, CE-CERT developed and operated the world's largest campus-based carsharing operation that relied heavily on a specific telematics architecture shown in Figure 2.1 (see [Barth & Todd, 1999; Barth et al, 2000a, 2000b, 2001a, 2001b, 2002a, 2002b]). Specific on-board hardware was developed and installed on nearly 50 vehicles, across four different vehicle types. This on-board hardware provided not only a means of monitoring a variety of vehicle functions (including location via GPS), it also was a critical part of vehicle access control. The hardware shown in Figure 2.2 consists of several useful attributes: 1) approximate two-meter positioning accuracy using an embedded differential GPS (DGPS) receiver; 2) two-way communications using an embedded general packet radio service (GPRS) modem; and 3) an embedded microcontroller that is programmable to perform a variety of tasks. UC Riverside's CE-CERT has extensive experience in on-board telematics systems, previously designing similar systems for carsharing operations, evaluating advanced fuel cell vehicles, and measuring vehicle activity.

In addition to this flexible on-board hardware system, web-based monitoring and control software has also been developed over the years. For the carsharing application, it was necessary to monitor vehicle status, provide access control by allowing registered users to gain entry with a smartcard system, and then log details of operation such as electric vehicle state-of-charge for all trips that are carried out in the system. This carsharing system operated for nine years, accumulating a database of over 100,000 trips. This database has been carefully analyzed and has resulted in numerous research papers.

This IntelliShare system has also been used to monitor vehicles in other research programs. For example, it is currently being used in monitoring Nissan Motor Company's fuel cell vehicle fleet that is currently deployed in California and Arizona, returning critical vehicle operational data to Nissan engineers as the vehicles are driven in the real-world (see [Nissan, 2004]). The system has also been deployed in a number of instrumented vehicles with the purpose of providing lane-level positioning accuracy (i.e., it reliably reports which lanes the instrumented vehicle is traveling in at any second) [Du, 2005; Barth & Du, 2005]. This hardware is now being slightly modified to carry out research in eco-friendly navigation, providing information to drivers about the most environmentally friendly route from a CO_2 and pollution point of view [Barth et al., 2007].

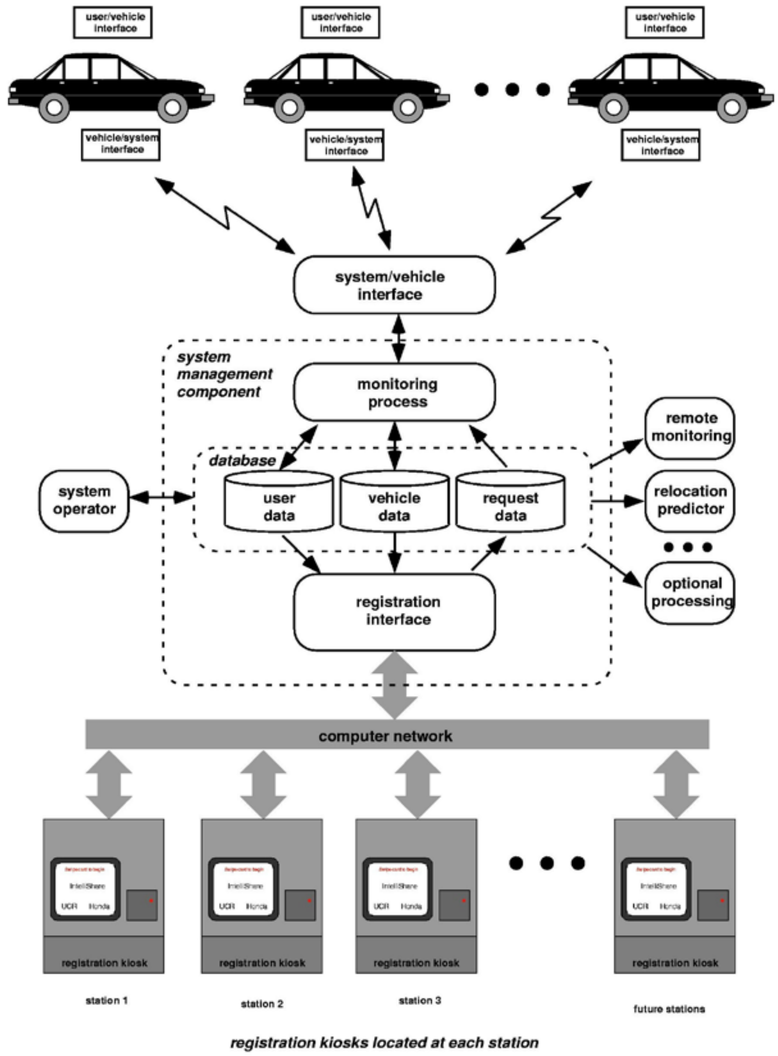
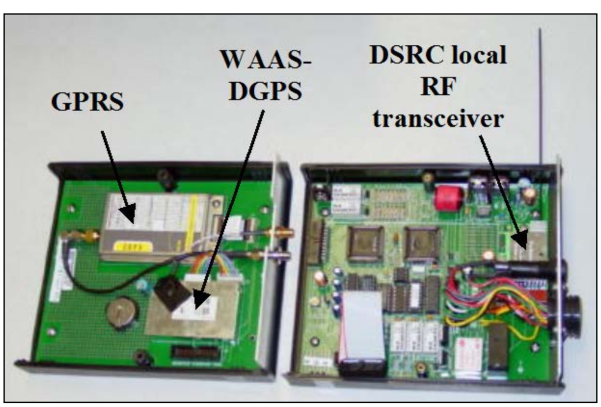


Figure 2.1. UCR IntelliShare carsharing system architecture.

a: 

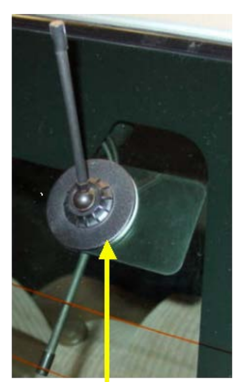
b: 

Figure 2.2. a) On-Board Telematics Hardware: GPRS - General Packet Radio Service cellular modem; WAAS-DGPS – Wide Area Augmentation System enabled Differential Global Position System receiver; DSRC – Dedicated Short Range Communications. **b)** Dual GPRS/GPS antenna.

2.2. Caltrans Ten Vehicle Pilot Program

During the Phase I and II pilot program a total of five vehicles were instrumented in Caltrans District 3 (Marysville) and five vehicles were instrumented in Caltrans District 11 (San Diego). The system server continues to reside at CE-CERT's research facilities. This server is accessible via the Internet by authorized Caltrans personnel 24 hours per day. District 3 E85 vehicles consisted of three 2008 Impalas and two 2007 Silverado's. District 11 provided three 2008 Impalas, one 2007 Silverado, and one 2008 Silverado. It is important to note that despite being the same model, the 2007 and 2008 Silverado's required a different interface protocol with the OBD-II data bus for ethanol fuel composition. The 2008 required specific PID addressing which was coordinated with engineers from GM.

Figure 2.3. Vehicles were simultaneously integrated with telematics to improve installation efficiency.

Each vehicle required several connections and hardware installation. These components and connections included:

- Power when key is on;
- Data signals from the OBD-II can bus;
- Vehicle ground through the OBD-II data connector; and,
- Antennae connection for Cellular;

The mounting location of the telematics hardware was selected for the proximity to the OBD-II data port and the antenna location on the dashboard. The mounting location for the Impala and Silverado are shown in Figure 2.5.

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vehid	vehvin	vehyear	vehmake	vehmodel	vehstyle	vehengine	vehlpn	vehstatus	vehequipid	vehsimid	vehbox
1	2G1WB58K481202548	2008	Chevy	Impala	Sedan		1283093	1	7005633	89014103212145442986	4
2	2GCEK133671677256	2008	Chevy	Impala	Sedan		1283046	1	7004835	89014103212145442994	3
3	2G1WB58K989288666	2008	Chevy	Impala	Sedan		1282962	1	7005055	89014103212145443026	8
4	2G1WB58K989288361	2008	Chevy	Impala	Sedan		1283010	1	7005059	89014103212145443042	7
5	2G1WB58K389287870	2008	Chevy	Impala	Sedan		1282963	1	7005637	89014103212145443034	6
6	1GCEC140X7Z609275	2007	Chevy	Silverado	Truck		1256534	1	7004568	89014103212145443000	2
7	1GCEC14007Z611455	2007	Chevy	Silverado	Truck		1256499	1	7004571	89014103212145442960	1
8	1GCEC14048Z258090	2008	Chevy	Silverado	Truck		1289251	1	7004862	89014103212145442978	5
9	1GCEK19007Z604338	2007	Chevy	Silverado	Truck		1256468	1	7004456	89014103212145443018	9
10	1GCEC190X7Z608538	2007	Chevy	Impala	Sedan		1256548	1	7004479	89014103212145443059	10
11	2G1WB58K281201334	2008	Chevy	Impala	Sedan		1283026	1	0000000	00000000000000000000	11

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in horizontal mode and repeat headers after 100 cells

Figure 2.4. Vehicle spreadsheet for vehicles equipped with telematics within District 3 and District 11.

Figure 2.5. Telematic units were installed within the dashboard on Silverado (left) and Impala (right).

After the alternative fueled vehicles were outfitted and the system server was operational, the first six-month pilot study was initiated. During this time, the vehicles were used for various purposes during normal operations. Their fuel use, fuel mixture, refueling locations, and total quantity of fuel purchased were recorded in the database, and this database was accessible to Caltrans TAG personnel for evaluation. Training was provided to the personnel as necessary so that they understand how to best use the system. In addition, regular teleconference meetings were held with the TAG for feedback and interaction.

Since the system architecture, design, implementation, and operation was new to Caltrans staff and TAG members, a project specific training and workshop was arranged for Districts 3 and 11. Members from the CE-CERT development team travelled to the districts and presented the system operation and how to utilize the web interface. A User's Guide was created, reviewed, and distributed. These training sessions allowed potential users and TAG members to critique the user interface and provide feedback to the development team. The training sessions were originally scheduled in the closing months of the project but were shifted to occur in coordination with the launch of the pilot program. The shift to an earlier date allowed users to become familiar with the system at the beginning of the pilot program versus the end.

The pilot study deployment consisted of 10 vehicles, with Districts 3 and 11 each providing 5 vehicles and staffing to coordinate with deployment and monitoring. During the 6 months of the pilot program the following data was collected:

- 3,965 trips with GPS location;
- 58,200 miles of OBDII monitoring;
- 3,514 gallons of fuel consumed with refueling event locations (47 % E85); and,
- 16.7 mpg average fuel economy.

Extensive data analysis was completed to better understand the vehicle activity, fuel use, and observable trends. The fuel use shown in Figure 2.6 details a greater amount of fuel use during the middle of the pilot program. Further analysis of vehicle activity and data reporting explains this trend being related to vehicle activity and refueling behavior. Figure 2.7 displays Phase I and II weekly trip totals and agrees with the fuel use trend seen in Figure 2.6. This data analysis has been summarized in the following graphs and figures.

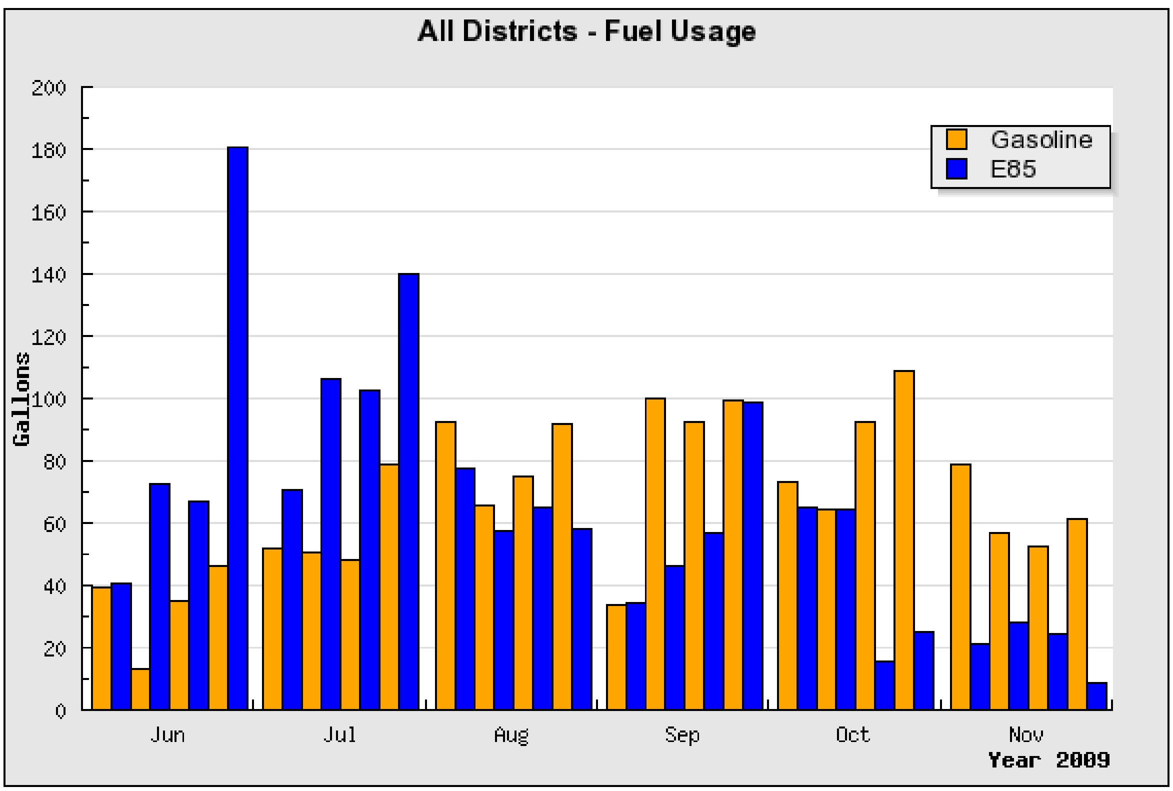


Figure 2.6. Weekly status of data collection vehicles operating in the pilot program.

To help clarify the fueling variability, the number of trips and miles travelled were evaluated for each week. Figure 2.7 shows the number of trips completed during the pilot program while Figure 2.8 displays the number of miles travelled. Evaluation of the three graphs indicates a greater amount of vehicle activity captured during the July/August time frame. Less vehicle activity was recorded in the beginning and end months of the study. This information was combined with further analysis to determine overall E85 fuel trends and presented in the Phase II final report.

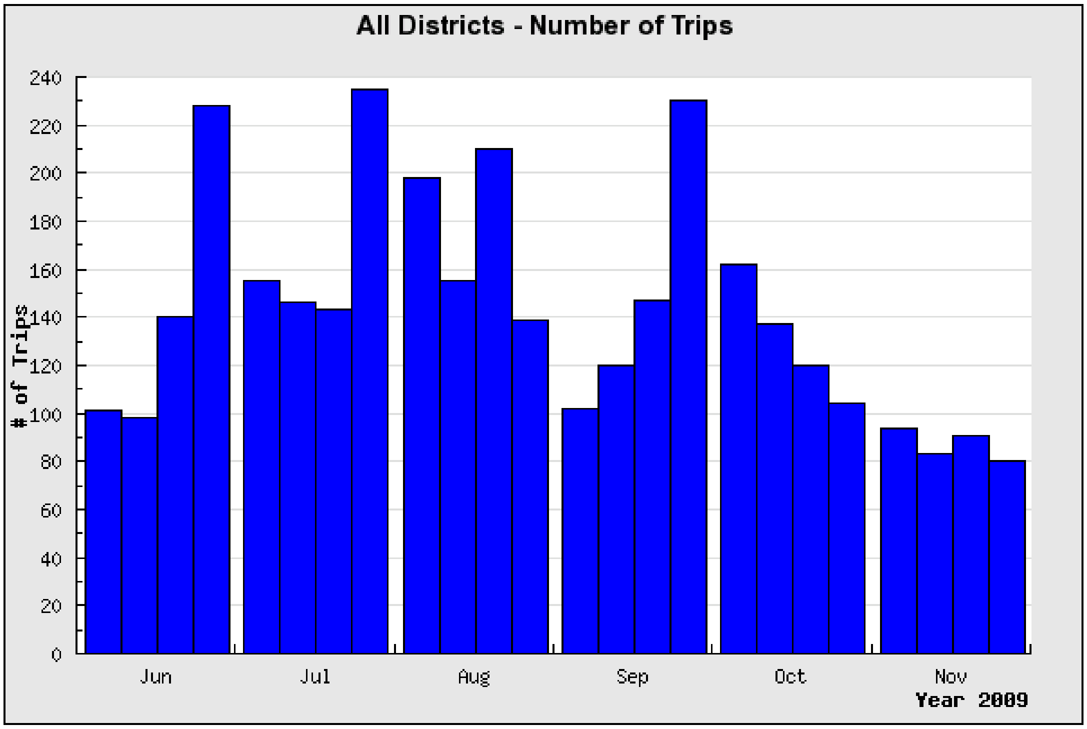


Figure 2.7. Weekly number of trips during the pilot program.

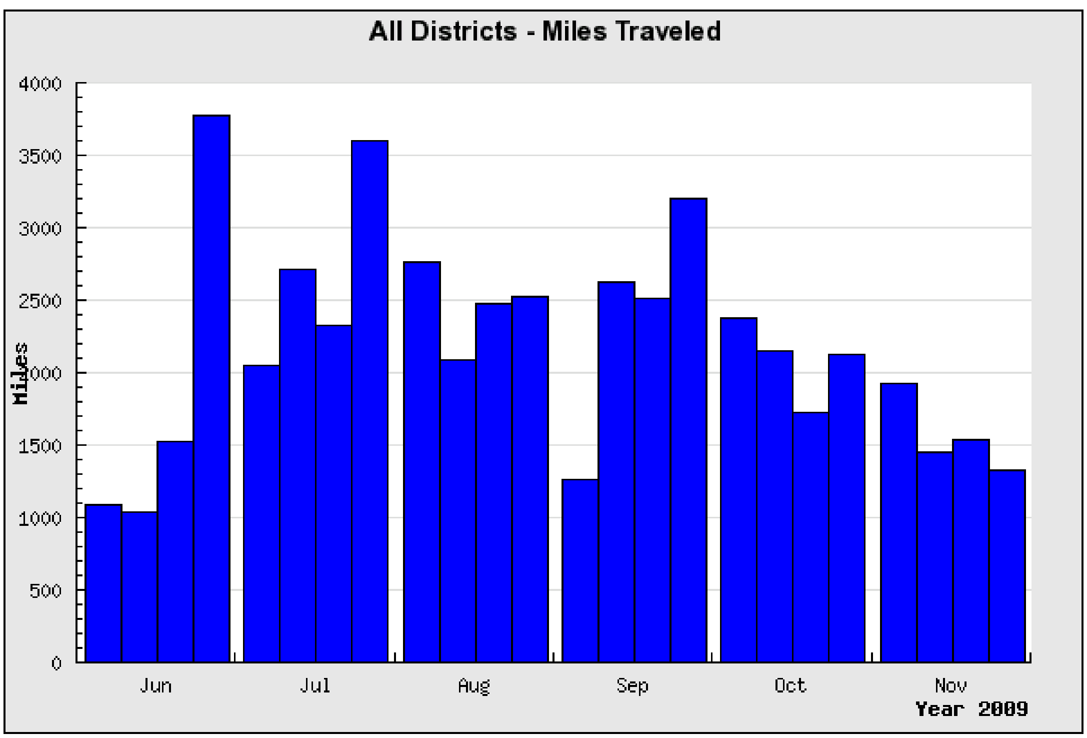


Figure 2.8. Weekly miles travelled during the pilot program.

3. VEHICLE HARDWARE DEPLOYMENT AND VENDOR PARTICIPATION

In order to remotely monitor a vehicle's E85 fuel usage, fuel mixture, and fueling locations and times, the architecture shown in Figure 3.1 has been implemented. This architecture is similar to the Phase I and II deployment with the addition of Wi-Fi communication. The architecture requires on-board vehicle telematics capable of tracking the vehicle using position information from the DGPS receiver. The on board telematics has the ability to communicate with the overall system through a cellular modem and/or Wi-Fi transceiver, sending information on the vehicle and its position. In addition, the microcontroller interfaces with the vehicle through the OBD-II data port. Details of this interfacing are described in the following section.

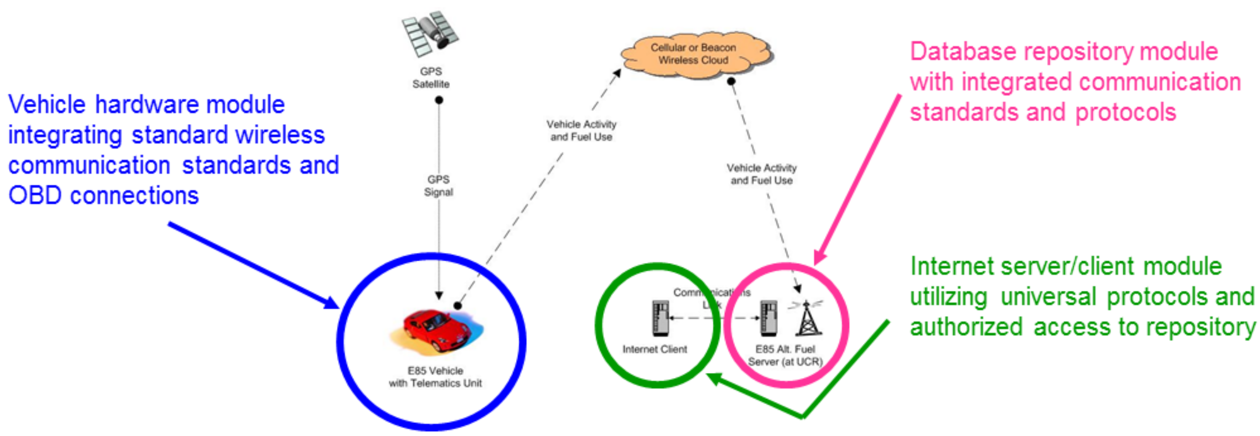


Figure 3.1. Phase III system architecture.

Based on the telematics hardware that has been tested previously, the research team procured 100 vehicle telematics units capable of integrating with Caltrans E85 vehicles. The vendor recruitment required each participating vendor to meet system requirements and data protocols. The participating vendors were required to interpret the E85 fuel composition parameter ID (PID) and make the data available to the E85 Alternative Fuel Server located at UC Riverside.

The telematics vendor hardware (Figure 3.2) required special programming to facilitate the interpretation of fuel composition on board each vehicle. The fuel composition of E85 vehicles can vary from 100 percent unleaded to 100 percent E85 (15 percent ethanol). Additionally, the fuel composition can vary after a refueling event due to the purging of prior fuel within the vehicle's fuel lines. Specifically for the fuel composition information, the Engine Control Module (ECM) on the E85 vehicles has a required input signal to identify the fuel composition for adjusting the Air to Fuel (A/F) ratio. This signal comes from an Original Equipment Manufacturer (OEM) computational method already existing on E85 vehicles.

Figure 3.2. On-board telematics vendor hardware.

On every vehicle that has an OBD-II interface, there are federally mandated engine and emission parameters available. It is from these parameters that we can obtain and estimate the fuel composition. To obtain fuel composition there are 7 PIDs (Parameter Ids) required. The PIDs are logged from engine start (key-on) to engine stop (key-off). The PIDs selected for this demonstration program are provided in Table 3.1.

Once a key-on event has occurred, all the selected PIDs are logged and recorded until a key-off event occurs. These parameters are logged and stored in telematic’s memory during the trip. At the end of the trip, the logged data is compressed and transmitted to the E85 Alt-Fuel server for post processing and storage. When the vehicle is lacking either cellular or Wi-Fi connection the data is stored until a valid connection exists. When the vehicle is equipped with only Wi-Fi communication, the vehicle activity data will be stored on-board until the vehicle has returned the district motorpool parking area.

Once the server has received the data from the vehicle, it validates the raw data and converts it to decimal values (from the raw hex format). This data is then processed by an algorithm that generates trip totals, which includes gallons of fuel and gallons of E85. During the processing of each second-by-second sample, three PIDs are crucial to obtaining the estimate for fuel composition, these are: Mass Air Flow (MAF) (PID 0x10), Ethanol Fuel % (PID 0x52), and Engine Run Time (PID 0x1F). From the MAF and engine run time values, the total gallons of fuel (Ethanol and Unleaded combined) consumed for the trip are determined. Once the total amount of fuel has been acquired the Ethanol Fuel % value for the trip is utilized to get the percent of the fuel that was E85.

PID Name	PID (Hex)	Description
Vehicle Speed	0x0D	Vehicle Speed in km/h
Mass Air Flow (MAF)	0x10	Mass of air intake into system (grams/second)
Engine Speed (RPM)	0x0C	Engine Speed - RPM (revolutions/minute)
Ethanol Fuel %	0x52	Percent Of Fuel that is Ethanol (0-100%)
Fuel Tank Level	0x2F	Fuel Tank Level (0-100%)
Engine Run Time	0x1F	Time in seconds that the engine has been running

Table 3.1. Selected OBD-II parameters on E85 GM vehicles.

3.1 Method for Obtaining Fuel Composition

Initial fuel composition analysis revealed unexplained variability and ethanol percentages lower than expected. Due to these observations, significant effort was utilized in determining and evaluating fuel composition. This section provides additional detail regarding the procedures and methods for determining fuel composition.

When classifying fuel, it is important to note that E85 is intended to be composed of 85 percent ethanol and 15 percent unleaded gasoline. The ethanol fuel composition (PID 0x52) value reports an approximate percent of ethanol in the fuel. For example, if your vehicle is running on pure E85, the vehicle will report a value approximate to 0.85 on PID 0x52. If a vehicle consumes 10 gallons of fuel (Ethanol and Unleaded combined) and it is found that the average ethanol fuel percent was 85 percent, then we would classify the fuel consumed for that trip as 10 gallons of E85 and 0 gallons of unleaded gasoline. It is important to note that although 15 percent of the fuel consumed was gasoline, we still consider the trip as pure E85. In another scenario, if a vehicle has an empty tank, and 5 gallons of unleaded gasoline and 5 gallons of pure E85 are added to the tank, the vehicle will report an ethanol fuel percent composition of 42.5 percent, not 50 percent. Although the vehicle is running on 50 percent unleaded and 50 percent E85, the vehicle will report the true ethanol composition.

To classify E85 and unleaded fuel consumption the following relationship was used:

Variable Definitions:

$x = \%$ Ethanol

$y = \%$ E85

Relationship:

$$\{0 \leq x \leq 10\} \quad y = 0\%$$

$$\{10 < x \leq 70\} \quad y = \left(\frac{100}{60}\right) \cdot x - \left(\frac{10 \cdot 100}{70}\right)$$

$$\{70 < x \leq 100\} \quad y = 100\%$$

The following Figure 3.3 graphically describes this relationship.

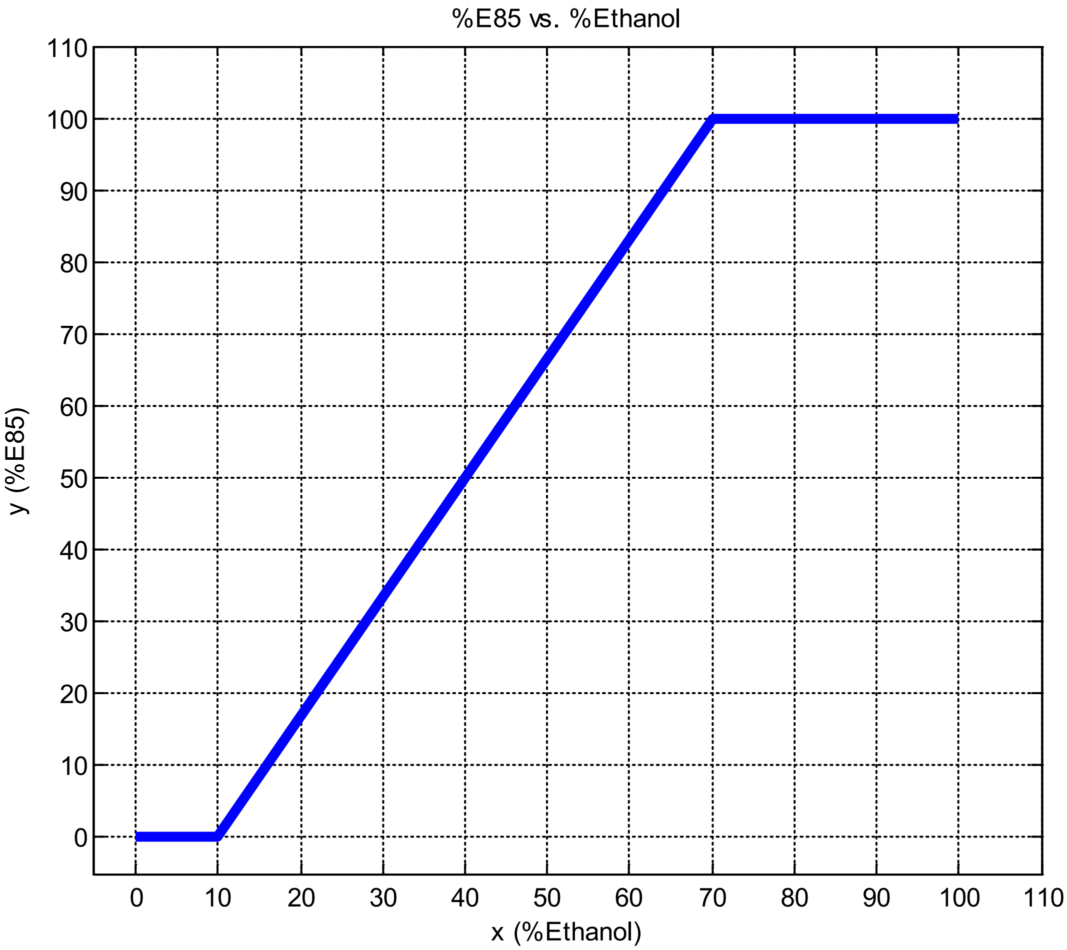


Figure 3.3. Ethanol value reported and corresponding E85 percent.

For this project 10 percent and 70 percent were chosen as the percent ethanol lower and upper thresholds respectively. The lower bound of 10 percent ethanol was selected, because any values of ethanol below 10 percent can be assumed to be running on pure unleaded (note: unleaded may contain up to 10 percent ethanol in California). The upper bound of 70 percent was chosen, because as mandated by the US DOE any fuel sold as E85 must have an ethanol content of at least 70 percent (U.S DOE 2006). It is also worth noting that the ethanol percentage of E85 can vary between 70-85 percent ethanol depending on geographic location and season.

The detailed testing and calibration of E85 measurements are provided in section 3.2 of the Phase II report.

4. SERVER AND USER INTERFACE DEVELOPMENT

System server enhancements allowed the integration and system expansion to include four districts and 100 vehicles. The server improvements encompassed both hardware and software modifications. In addition to configuring the server hardware and operating system, three separate processes (programs) were enhanced and upgraded:

1) ***A Communications Interface*** - interfaces with vendor servers and a cellular data Internet site in order to receive the packets sent out by the individual vehicles. The data paths are generated, allowing for the packets to be received. Specific application program interfaces (APIs) were created along vendor data integration. Additionally, Wi-Fi based data routing was integrated within the communications interface. This communications interface interprets the data packet and time-stamps data parameters into a SQL database. This database is accessible from other processes operating on the server computer.

2) ***Database Manager*** - maintains and updates tables and data fields. This database architecture and structure is shown in Figure 4.1. The database manager is organized such that the system is expandable to thousands of vehicles and users. Additionally, the database architecture allows for flexibility of vehicle types and trip parameters.

3) ***User Interface*** - makes the connection between the database and the Internet. An authorized user (e.g., Caltrans user/manager/liaison) is able to log into the system server from any Internet connected computer and be able to access the data. The added functionality of a manager/liaison is shown in Figure 4.2. In general, the database is organized on a trip-basis (i.e., trip information such as start time, end time, fuel used, fuel mixture, etc.). In addition, several database queries have been developed that allow for the determination of generalized trip statistics such as average fuel use, fuel type, etc. Further, it is possible to import these results into spreadsheets for reporting purposes. Since the data will be spatially and temporally tagged, a GIS (Geographical Information System) Graphical User Interface (GUI) was developed for displaying trips on a map (Figure 4.3).

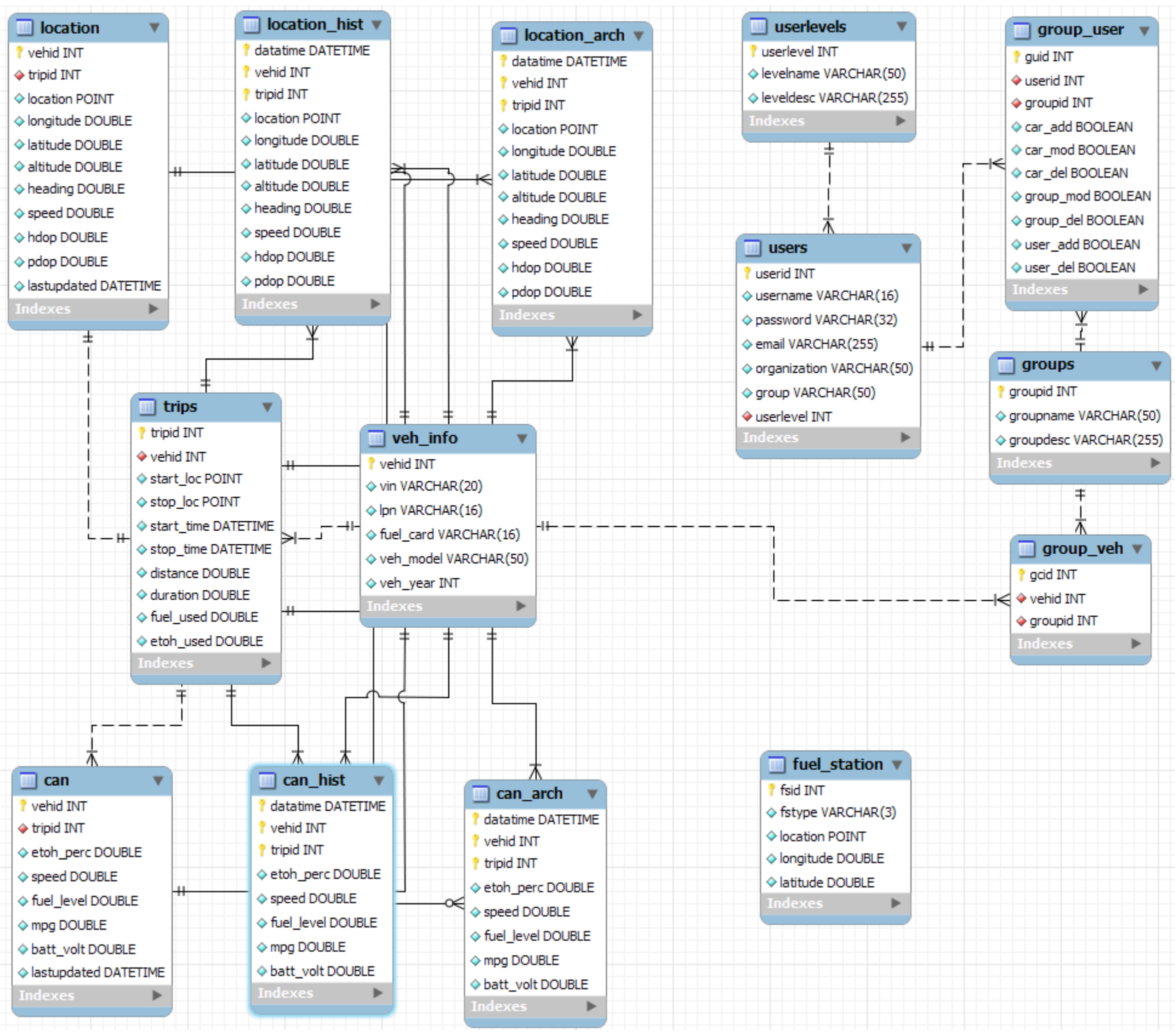


Figure 4.1. Database structure for the E85 alt fuel server.

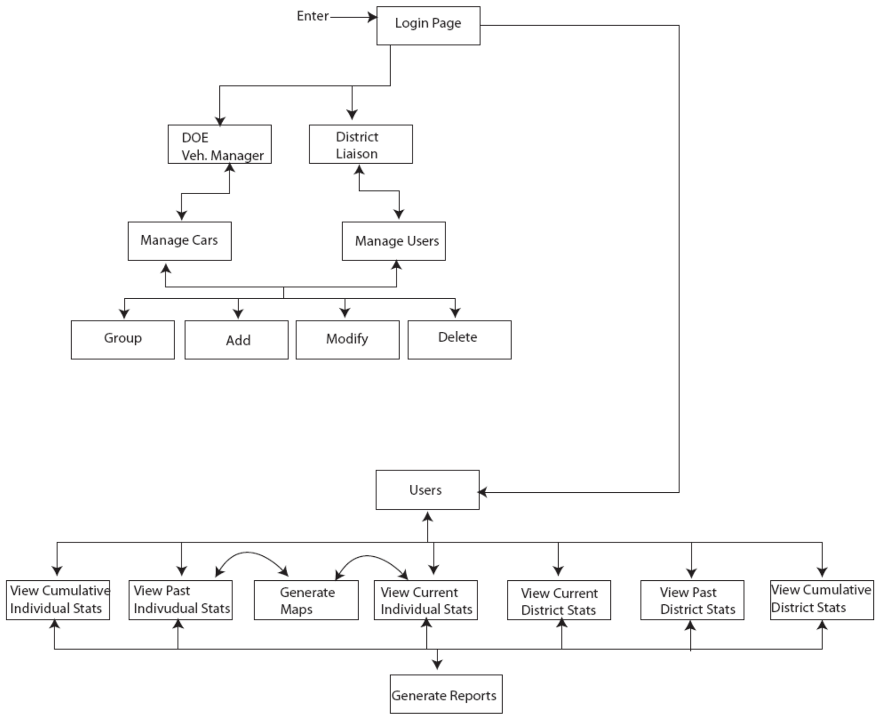


Figure 4.2. User structure for the E85 alt fuel server.

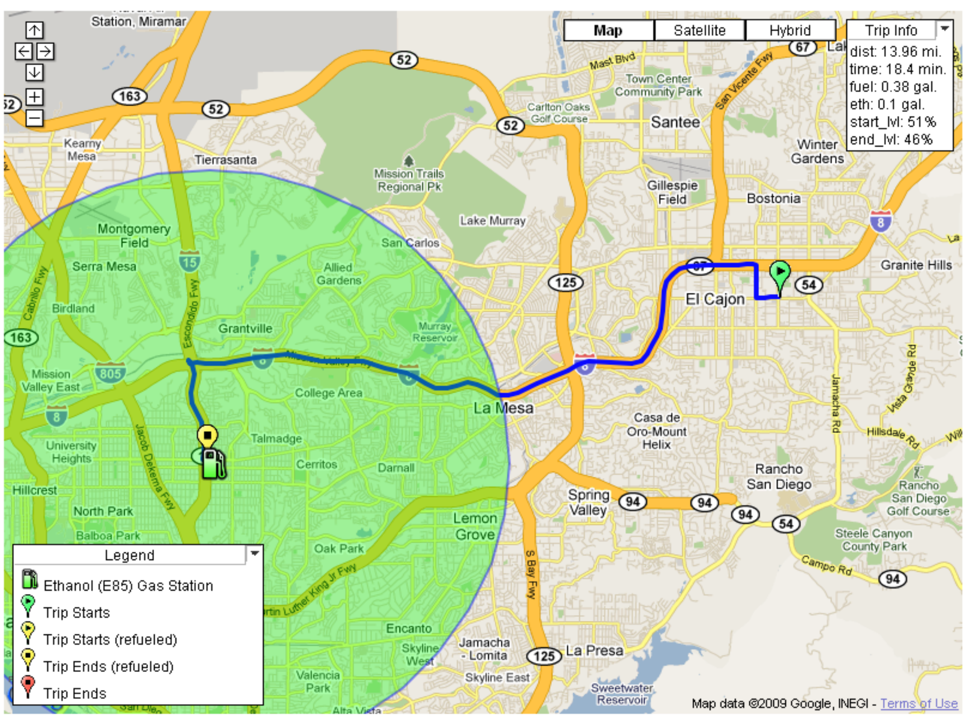


Figure 4.3. User interface and GUI for trip mapping.

4.1 Web Based Graphical User Interface

The research team has extensive experience in developing web-based applications as demonstrated during the Phase I and Phase II research and deployment. The system server receives data on Wi-Fi and cellular networks which interface to the server via a specific Internet site. Using UDP/TCP and TCP/IP messaging, packets are transmitted between cellular modem and/or Wi-Fi transceiver on each vehicle and the system server. The system server logs all data in a local SQL database for further analysis. In addition, the system server provides a means to observe the data using a graphical user interface. The server is configured to allow for remote access from other authorized users on the Internet.

The web based application provides numerous functions to Caltrans personnel:

- Summary of fuel usage in the previous days and week (Figure 4.4);
- Vehicle specific information for department use (Figure 4.5);
- Trip sorting and queries by date and vehicle number (Figure 4.6);
- Trip mapping functionality for specific trips (Figures 4.7 and 4.8);
- E85 re-fueling location mapping (Figure 4.9); and,
- Data exporting for additional analysis and evaluation.

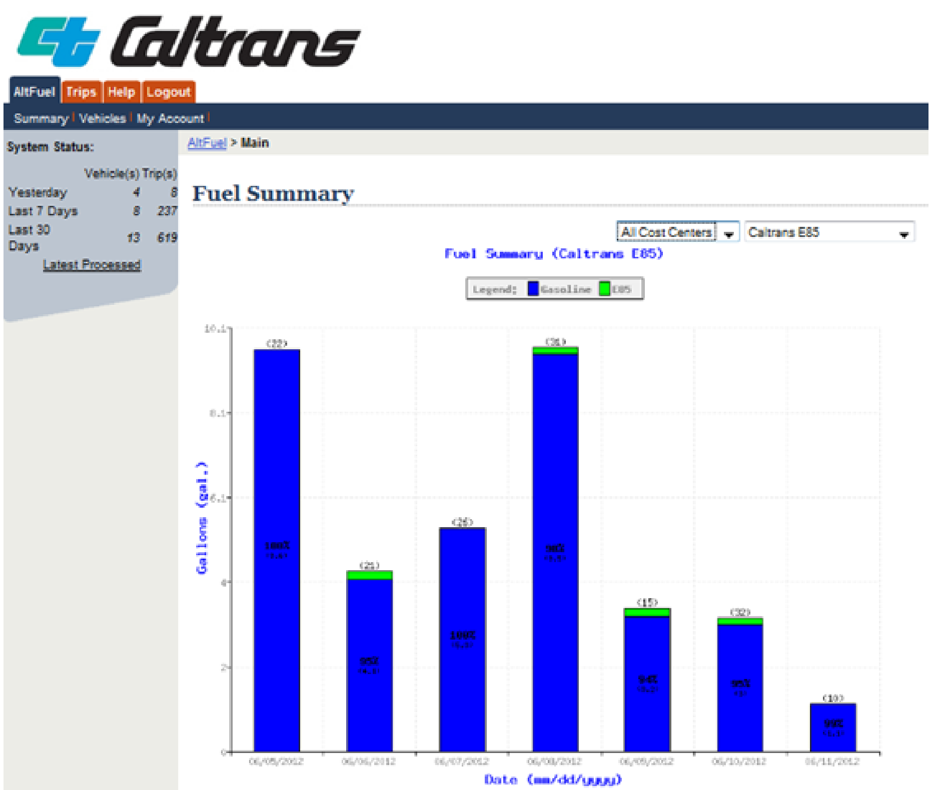


Figure 4.4. Summary page on the E85 alternative fuel server web interface.

The home summary page is where the user arrives after logging in with a secure User ID and Password. The page is organized with tabs and menus for performing the various functions on the web site. As requested by the Caltrans Task Advisory Group (TAG), the capabilities of the interface are tiered dependent upon user classification. Managers and Fleet Liaisons have rights to modify user accounts and review trip specifics (such as speed and location data). General users are able to login and review general fuel usage and vehicle data.

The vehicle mapping GUI shown in Figures 4.7 and 4.8 provides detailed information regarding a specific trip. Refueling events are identified with icons at the beginning and/or end of trip. Figure 4.7 shows a pre-refueling trip while 4.8 displays a post-refueling trip. Trip distance, time, fuel used, and ethanol percentages are provided in a summary window. Any trip from any vehicle collected on the server can be displayed with the map view. The specific E85 refueling locations are shown as a green fuel pump icon. Figure 4.9 shows the E85 map location for all District 11 E85 refueling locations.

To show data in a tabular form, a specific query function exists. The query function allows a user to sort by vehicle, district, and date range. An example of the reported data from the query is shown in Figure 4.6. The icons along the right margin provide the ability to display additional trip details. The globe icon will present the map GUI while the spreadsheet icons will display tabular trip data of vehicle position and/or OBD-II parameters.

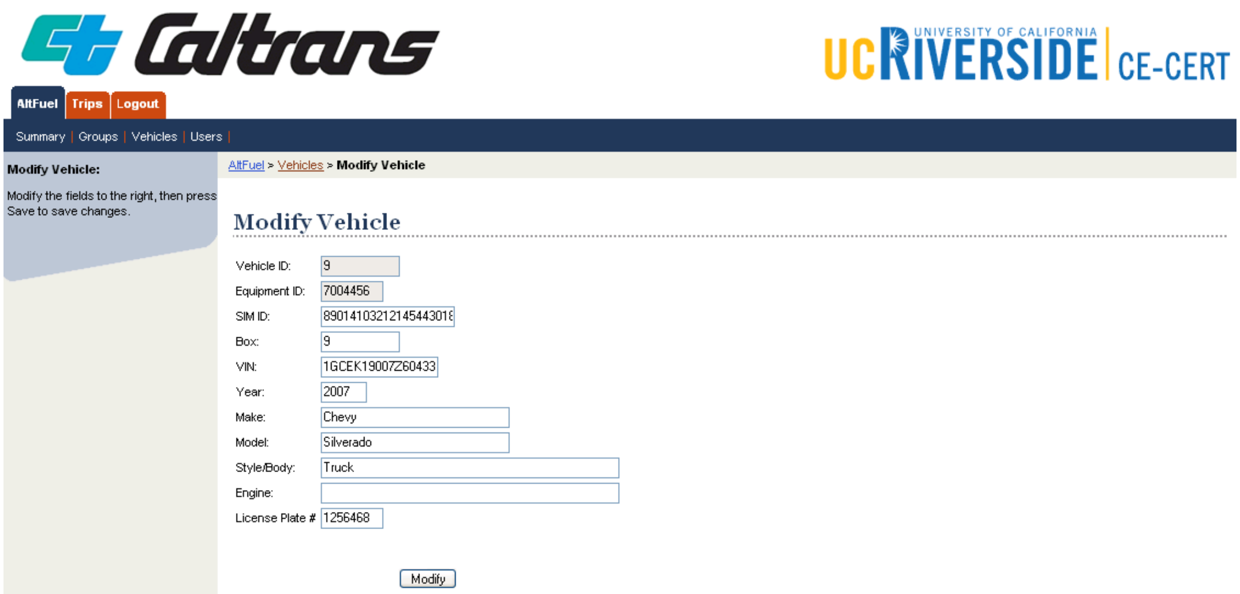
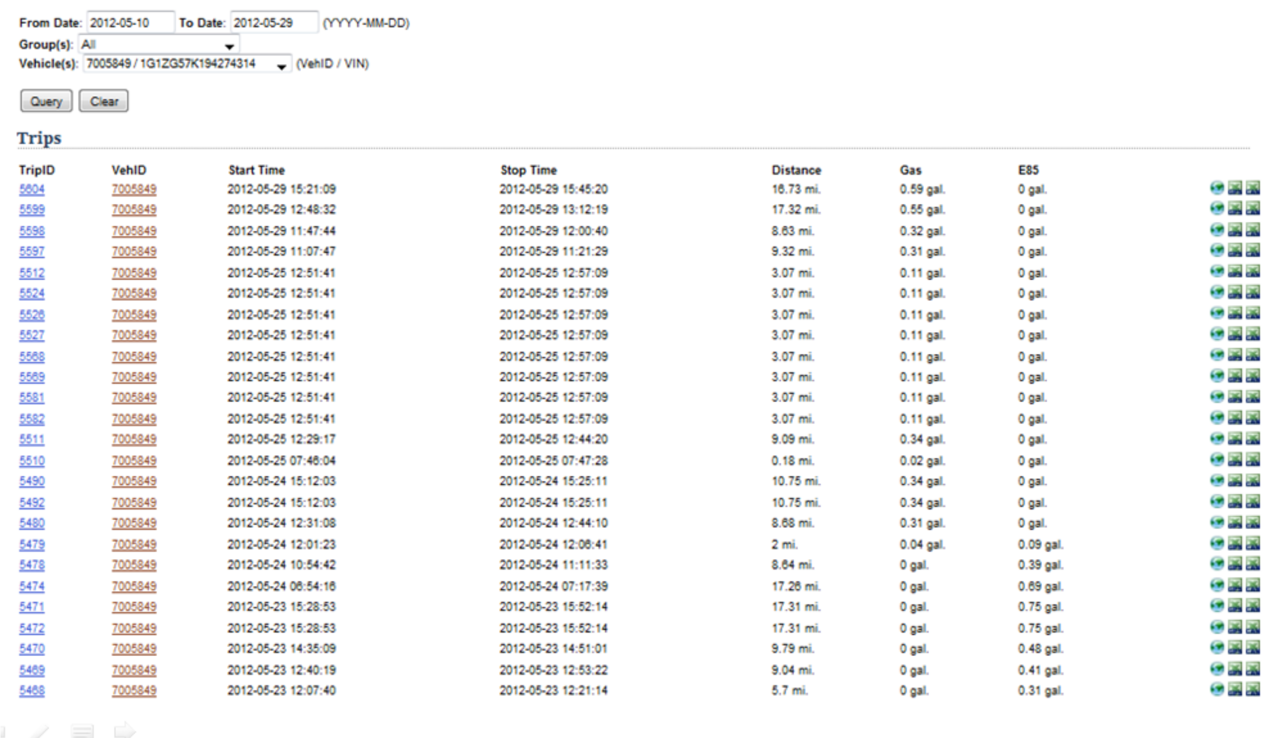


Figure 4.5. Vehicle data page for vehicle specific information.



From Date: 2012-05-10 To Date: 2012-05-29 (YYYY-MM-DD)
Group(s): All
Vehicle(s): 7005849 / 1G1ZG57K194274314 (VehID / VIN)
Query Clear

Trips

TripID	VehID	Start Time	Stop Time	Distance	Gas	E85
5604	7005849	2012-05-29 15:21:09	2012-05-29 15:45:20	16.73 mi.	0.59 gal.	0 gal.
5599	7005849	2012-05-29 12:48:32	2012-05-29 13:12:19	17.32 mi.	0.55 gal.	0 gal.
5598	7005849	2012-05-29 11:47:44	2012-05-29 12:00:40	8.63 mi.	0.32 gal.	0 gal.
5597	7005849	2012-05-29 11:07:47	2012-05-29 11:21:29	9.32 mi.	0.31 gal.	0 gal.
5512	7005849	2012-05-25 12:51:41	2012-05-25 12:57:09	3.07 mi.	0.11 gal.	0 gal.
5524	7005849	2012-05-25 12:51:41	2012-05-25 12:57:09	3.07 mi.	0.11 gal.	0 gal.
5526	7005849	2012-05-25 12:51:41	2012-05-25 12:57:09	3.07 mi.	0.11 gal.	0 gal.
5527	7005849	2012-05-25 12:51:41	2012-05-25 12:57:09	3.07 mi.	0.11 gal.	0 gal.
5568	7005849	2012-05-25 12:51:41	2012-05-25 12:57:09	3.07 mi.	0.11 gal.	0 gal.
5569	7005849	2012-05-25 12:51:41	2012-05-25 12:57:09	3.07 mi.	0.11 gal.	0 gal.
5581	7005849	2012-05-25 12:51:41	2012-05-25 12:57:09	3.07 mi.	0.11 gal.	0 gal.
5582	7005849	2012-05-25 12:51:41	2012-05-25 12:57:09	3.07 mi.	0.11 gal.	0 gal.
5511	7005849	2012-05-25 12:29:17	2012-05-25 12:44:20	9.09 mi.	0.34 gal.	0 gal.
5510	7005849	2012-05-25 07:46:04	2012-05-25 07:47:28	0.18 mi.	0.02 gal.	0 gal.
5490	7005849	2012-05-24 15:12:03	2012-05-24 15:25:11	10.75 mi.	0.34 gal.	0 gal.
5492	7005849	2012-05-24 15:12:03	2012-05-24 15:25:11	10.75 mi.	0.34 gal.	0 gal.
5480	7005849	2012-05-24 12:31:08	2012-05-24 12:44:10	8.68 mi.	0.31 gal.	0 gal.
5479	7005849	2012-05-24 12:01:23	2012-05-24 12:06:41	2 mi.	0.04 gal.	0.09 gal.
5478	7005849	2012-05-24 10:54:42	2012-05-24 11:11:33	8.64 mi.	0 gal.	0.39 gal.
5474	7005849	2012-05-24 06:54:16	2012-05-24 07:17:39	17.26 mi.	0 gal.	0.69 gal.
5471	7005849	2012-05-23 15:28:53	2012-05-23 15:52:14	17.31 mi.	0 gal.	0.75 gal.
5472	7005849	2012-05-23 15:28:53	2012-05-23 15:52:14	17.31 mi.	0 gal.	0.75 gal.
5470	7005849	2012-05-23 14:35:09	2012-05-23 14:51:01	9.79 mi.	0 gal.	0.48 gal.
5469	7005849	2012-05-23 12:40:19	2012-05-23 12:53:22	9.04 mi.	0 gal.	0.41 gal.
5468	7005849	2012-05-23 12:07:40	2012-05-23 12:21:14	5.7 mi.	0 gal.	0.31 gal.

Figure 4.6. Tabular data resulting from a trip query.

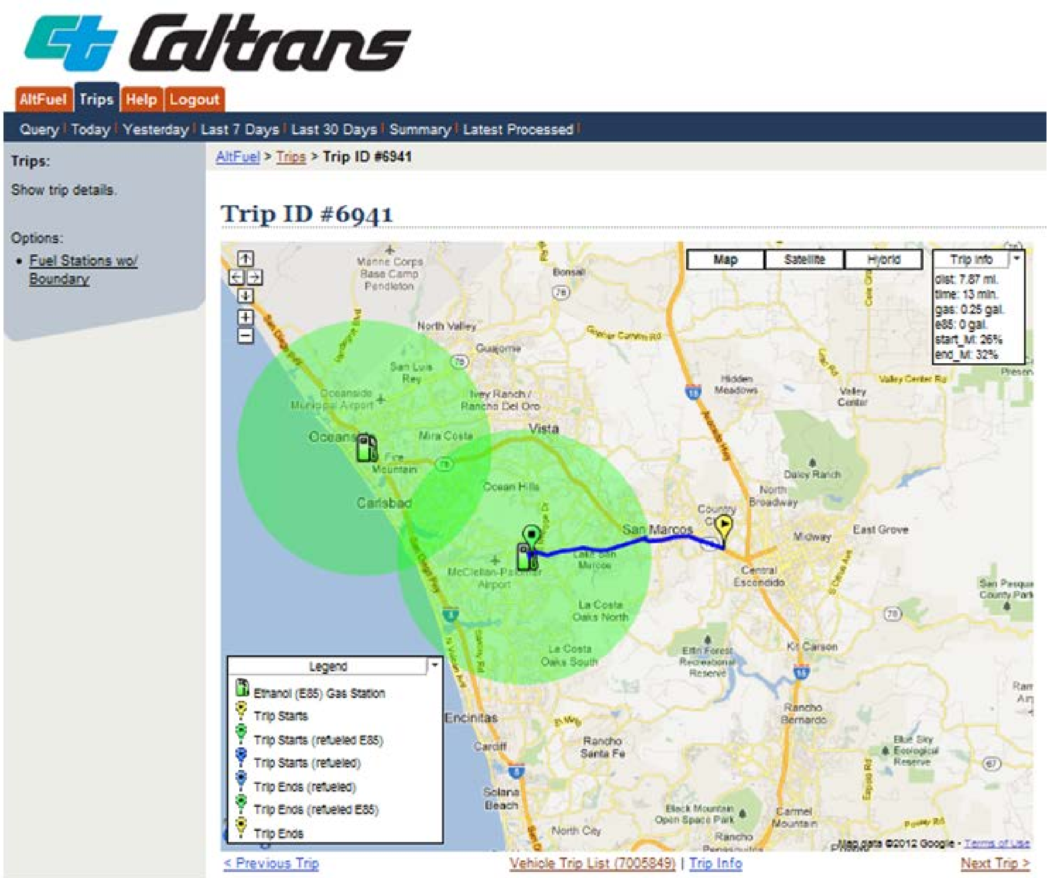


Figure 4.7. Pre-refueling trip detail map page.

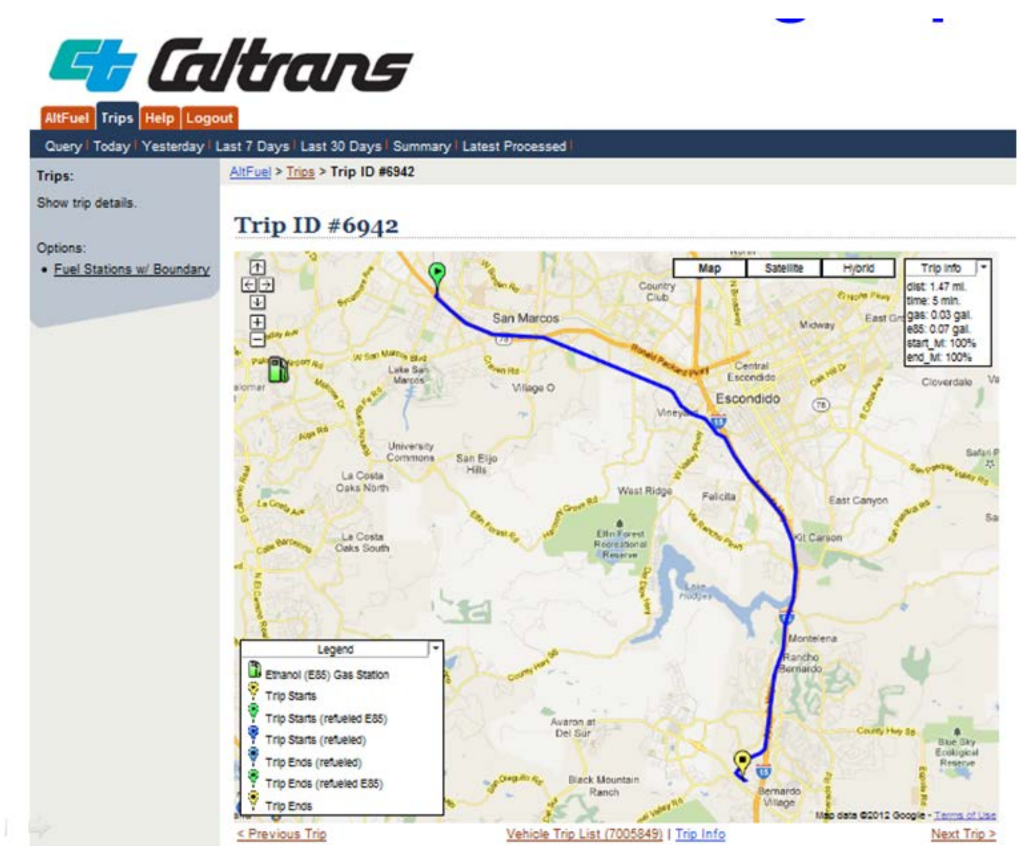


Figure 4.8. Post-refueling trip detail map page.

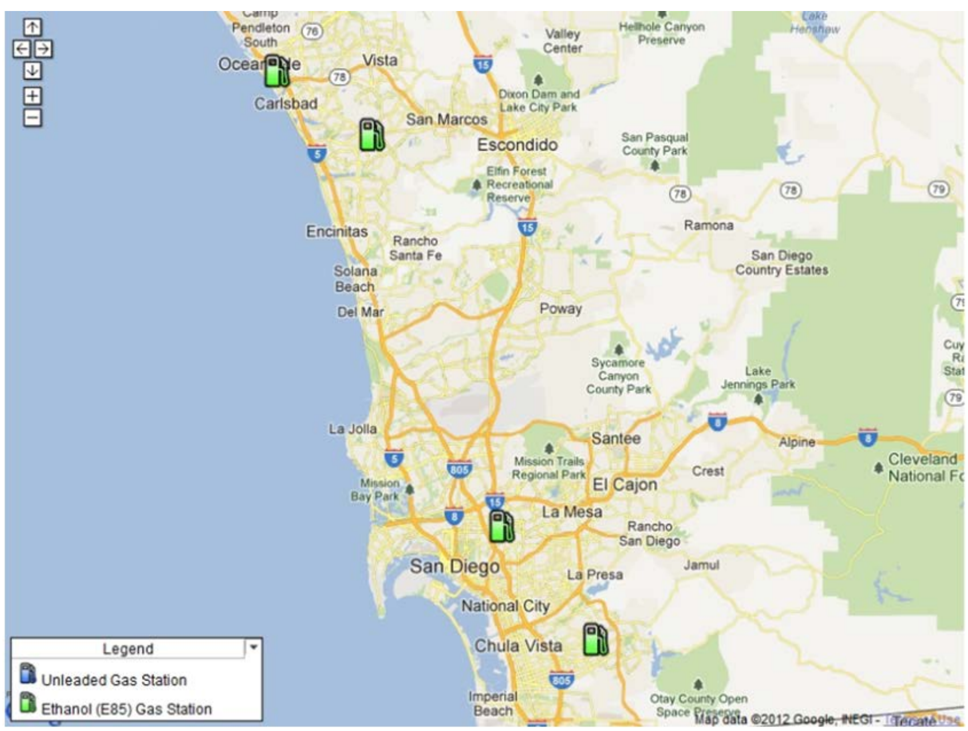


Figure 4.9. E85 District 11 E85 refueling locations.

5. DISTRICT AND VEHICLE INSTALLATION

5.1 Vehicle Installation

Phase III system expansion required the integration of several new vehicle models spanning numerous production years. After the initial vehicle integration had been demonstrated for each model/year combination by UCR staff, equivalent vehicles were provided to vendors for equipment installation. The level of effort of this task was greatly improved by perfecting the installation on individual vehicle models during Phases I and II. The necessary parameters were obtained through the OBD-II data bus; therefore, additional sensors and line-tapping were not necessary. TAG members at each district were able to provide a clean and convenient location for the installation process to occur quickly (Figure 5.1). Additionally, all the vehicles were made available at the same time and at each location, which streamlined the process and allowed for faster integration (Figure 5.2).

A total of 100 vehicles were instrumented in Caltrans District 4, District 7, District 8, and District 11. District 3 only participated in Phase II and did not participate in Phase III deployments. The system server continues to reside at CE-CERT's research facilities. This server is accessible via the Internet by authorized Caltrans personnel 24 hours per day. District 4 provided 20 vehicles consisting of 18 Impalas and two Uplanders. District 7 provided 25 vehicles consisting of Impalas, Malibus, and a single Silverado. District 8 is consists of a 30 vehicle installation of Silverados, Impalas, and one Uplander. District 11 provided 25 vehicles consisting of Impalas, Silverados, Malibus, and two Uplanders. It is important to note that despite being the same model, the 2007 and 2008 Silverados required a different interface protocol with the OBD-II data bus for ethanol fuel composition. The 2008 required specific PID addressing which was coordinate with engineers from GM.

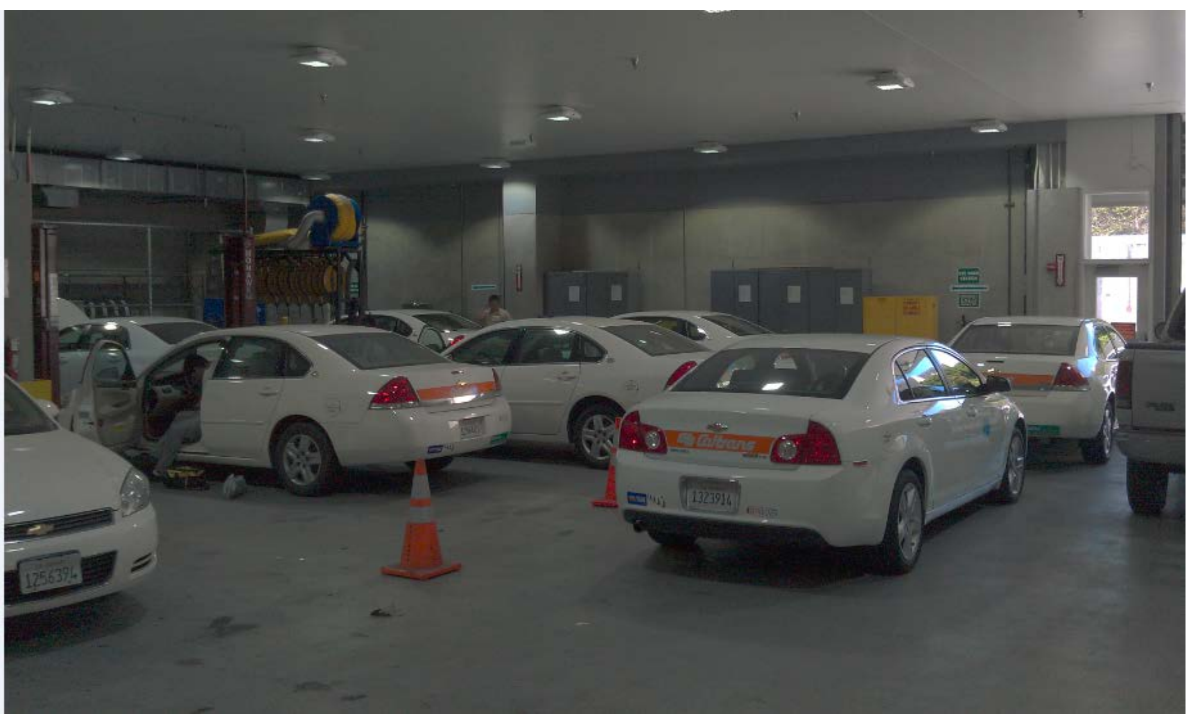


Figure 5.1. Vehicles were simultaneously integrated with telematics to improve installation efficiency.

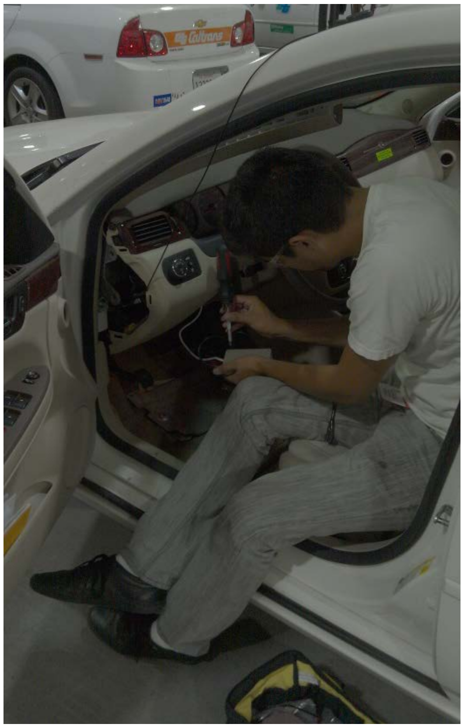
Figure 5.2. Large quantities of vehicles were provided concurrently to expedite installation.

Each vehicle required several connections associated with the telematic hardware installation. These components and connections included:

- Power when key is on;
- Data signals from the OBD-II can bus;
- Vehicle ground through the OBD-II data connector;
- Antennae connection for Cellular; and,
- Antennae connection for GPS.

The mounting location of the telematics hardware was reviewed for specific vendor requirements. Vendor specific cables were installed when necessary to provide access to the antenna location on the dashboard. The installation procedure and individual vehicle programming are shown in Figure 5.3.

A total of 100 vehicles were installed with a combination of vendor supplied hardware (75 units) and UCR procured (25 units) hardware. The vehicle installations were distributed across four districts with vehicle details provided in the subsequent figures. Vehicle information for Districts 4, 7, 8, and 11 are provided in Figures 5.4, 5.5, 5.6 and 5.7, respectively.



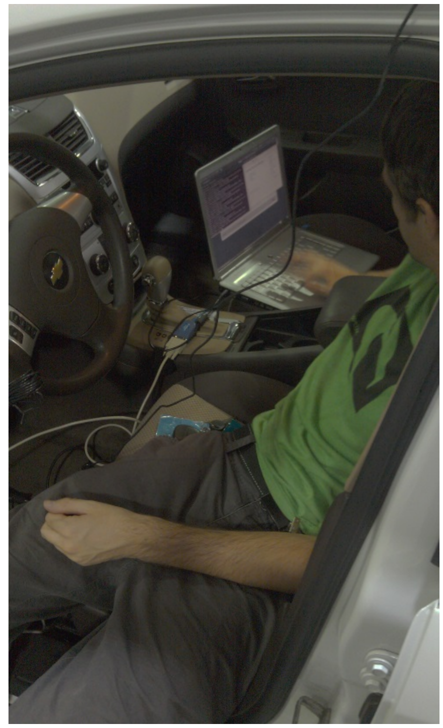


Figure 5.3. Telematic units were installed (left) and programmed for specific vehicle requirements (right).

District 04

California Department of Transportation - District 04

Users

Found 0 user(s).

Vehicles

VehID	VIN	Year/Make/Model		
7003893	2G1WB58K079363866	2007 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7004389	1GNDV23W17D216741	2007 Chevrolet Uplander		
7004390	1GNDV23W67D215651	2007 Chevrolet Uplander	04-0570	AUTOMOTIVE POOL
7005468	2G1WB58K889283930	2008 Chevrolet Impala		
7005470	2G1WB58K289287441	2008 Chevrolet Impala		
7005473	2G1WB58K589288373	2008 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7005478	2G1WB58K889286732	2008 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7005479	2G1WB58K289283857	2008 Chevrolet Impala		
7005481	2G1WB58K989287873	2008 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7005485	2G1WB58K189283736	2008 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7005489	2G1WB58KX89288563	2008 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7005491	2G1WB58KX89287672	2008 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7005506	2G1WB58K481203831	2008 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7005509	2G1WB58K981201296	2008 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7005513	2G1WB58K781204052	2008 Chevrolet Impala		
7005618	2G1WB58K481203859	2008 Chevrolet Impala	04-0570	AUTOMOTIVE POOL
7006330	1G1ZG57K494270337	2009 Chevrolet Malibu	04-0570	AUTOMOTIVE POOL
7006331	1G1ZG57K794269652	2009 Chevrolet Malibu		
7006332	1G1ZG57K894269109	2009 Chevrolet Malibu		
7006333	1G1ZG57K994270107	2009 Chevrolet Malibu	04-0570	AUTOMOTIVE POOL

Figure 5.4. District 4 vehicle installation list.

District 07

California Department of Transportation - District 07

Users

Found 0 user(s).

Vehicles

VehID	VIN	Year/Make/Model		
7004043	2G1WB58K479367970	2007 Chevrolet Impala	07-1688	AUTOMOTIVE POOL
7004115	2G1WB58K379364445	2007 Chevrolet Impala	07-1688	AUTOMOTIVE POOL
7004117	2G1WB58K779371253	2007 Chevrolet Impala	07-1688	AUTOMOTIVE POOL
7004118	2G1WB58K379374716	2007 Chevrolet Impala	07-1688	AUTOMOTIVE POOL
7004121	2G1WB58K279374867	2007 Chevrolet Impala	07-1688	AUTOMOTIVE POOL
7004122	2G1WB58K979372467	2007 Chevrolet Impala		
7004123	2G1WB58K279372889	2007 Chevrolet Impala	07-1688	AUTOMOTIVE POOL
7004126	2G1WB58K279340640	2007 Chevrolet Impala	07-1688	AUTOMOTIVE POOL
7004132	2G1WB58KX79341650	2007 Chevrolet Impala		
7004135	2G1WB58K579343130	2007 Chevrolet Impala		
7004154	1GCEC14057Z606770	2007 Chevrolet Silverado		
7005299	2G1WB58K881204383	2008 Chevrolet Impala	07-1688	AUTOMOTIVE POOL
7005314	2G1WB58K481204364	2008 Chevrolet Impala	07-1688	AUTOMOTIVE POOL
7006057	1G1ZG57K294270451	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL
7006061	1G1ZG57K394271219	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL
7006066	1G1ZG57K494270421	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL
7006069	1G1ZG57K794271014	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL
7006076	1G1ZG57K694269772	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL
7006080	1G1ZG57K294269784	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL
7006090	1G1ZG57K894269787	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL
7006091	1G1ZG57KX94269564	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL
7006096	1G1ZG57KX94269791	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL
7006101	1G1ZG57K194269517	2009 Chevrolet Malibu	07-1688	AUTOMOTIVE POOL

Figure 5.5. District 7 vehicle installation list.

District 08

California Department of Transportation - District 08

Users

Found 0 user(s).

Vehicles

VehID	VIN	Year/Make/Model		
7004010	1GNDV23W17D217954	2007 Chevrolet Uplander	08-2146	AUTOMOTIVE POOL
7004914	2G1WB58K681203748	2008 Chevrolet Impala	08-2231	DESIGN
7004915	2G1WB58K281201334	2008 Chevrolet Impala	08-2146	AUTOMOTIVE POOL
7004916	2G1WB58K381201343	2008 Chevrolet Impala	08-2146	AUTOMOTIVE POOL
7004917	2G1WB58K081205785	2008 Chevrolet Impala	08-2146	AUTOMOTIVE POOL
7004918	2G1WB58K381201228	2008 Chevrolet Impala	08-2146	AUTOMOTIVE POOL
7004921	2G1WB58K281201575	2008 Chevrolet Impala	08-2146	AUTOMOTIVE POOL
7004922	1GCEC140X8Z259034	2008 Chevrolet 1500	08-2293	PERMITS
7004923	2G1WB58K181203088	2008 Chevrolet Impala	08-2146	AUTOMOTIVE POOL
7004924	2G1WB58K981201010	2008 Chevrolet Impala	08-2146	AUTOMOTIVE POOL
7004927	2G1WB58K081202983	2008 Chevrolet Impala	08-2146	AUTOMOTIVE POOL
7004929	2G1WB58K981202058	2008 Chevrolet Impala	08-2146	AUTOMOTIVE POOL
7004930	2G1WB58K781201748	2008 Chevrolet Impala	08-2231	DESIGN
7004942	1GCEC14008Z257650	2008 Chevrolet 1500	08-2324	FIELD CONST
7004945	1GCEC14098Z258912	2008 Chevrolet 1500	08-2332	CONST LAB
7004948	1GCEC19008Z264543	2008 Chevrolet 1500	08-2327	FIELD CONST
7004949	1GCEC19018Z264079	2008 Chevrolet 1500	08-2333	CONST LAB
7004951	1GCEC19028Z265063	2008 Chevrolet 1500	08-2324	FIELD CONST
7004955	1GCEC19038Z261376	2008 Chevrolet 1500	08-2324	FIELD CONST
7004956	1GCEC19058Z262349	2008 Chevrolet 1500	08-2326	FIELD CONST
7004957	1GCEC19048Z264013	2008 Chevrolet 1500	08-2325	FIELD CONST
7004958	1GCEC190X8Z264453	2008 Chevrolet 1500	08-2324	FIELD CONST
7004962	1GCEC19088Z263320	2008 Chevrolet 1500	08-2332	CONST LAB

Figure 5.6. District 8 vehicle installation list.

District 11

California Department of Transportation - District 11

Users

Found 0 user(s).

Vehicles

VehID	VIN	Year/Make/Model		
7003622	2G1WB55K269382941	2006 Chevrolet Impala	11-2673	AUTOMOTIVE POOL
7003626	2G1WB55K269382101	2006 Chevrolet Impala	11-2799	SURVEYS
7003627	2G1WB55K169380243	2006 Chevrolet Impala		
7004020	1GNDV23W27D217297	2007 Chevrolet Uplander	11-2673	AUTOMOTIVE POOL
7004568	1GCEC140X7Z609275	2007 Chevrolet Silverado	11-2850	FIELD CONST
7004571	1GCEC14007Z611455	2007 Chevrolet Silverado	11-2850	FIELD CONST
7004835	2G1WB58K481204980	2008 Chevrolet Impala	11-2673	AUTOMOTIVE POOL
7004836	2G1WB58K181203544	2008 Chevrolet Impala	11-2673	AUTOMOTIVE POOL
7004837	2G1WB58K181205004	2008 Chevrolet Impala	11-2850	FIELD CONST
7004838	2G1WB58K581203272	2008 Chevrolet Impala	11-2673	AUTOMOTIVE POOL
7004840	2G1WB58K481205014	2008 Chevrolet Impala	11-2673	AUTOMOTIVE POOL
7004841	2G1WB58K081203230	2008 Chevrolet Impala	11-2673	AUTOMOTIVE POOL
7004844	2G1WB58K781202561	2008 Chevrolet Impala	11-2673	AUTOMOTIVE POOL
7004855	1GNDU23W88D202159	2008 Chevrolet Uplander	11-2799	SURVEYS
7005633	2G1WB58K481202548	2008 Chevrolet Impala	11-2850	FIELD CONST
7005849	1G1ZG57K194274314	2009 Chevrolet Malibu	11-2850	FIELD CONST
7005852	1G1ZG57K894269756	2009 Chevrolet Malibu	11-2850	FIELD CONST
7005857	1GCEC14069Z243043	2009 Chevrolet Silverado	11-2850	FIELD CONST
7005864	1GCEC140X9Z245488	2009 Chevrolet Silverado	11-2850	FIELD CONST
7005866	1GCEC14029Z245498	2009 Chevrolet Silverado		
7005951	1G1ZG57K994269247	2009 Chevrolet Malibu		
7006341	1G1ZG57K994269443	2009 Chevrolet Malibu		

Figure 5.7. District 11 vehicle installation list.

5.2 Motorpool Wi-Fi Installation

Each participating district location operates a motorpool consisting of numerous E85 sedan vehicles. To evaluate the benefits and potential cost savings associated with Wi-Fi communications, the motorpool vehicles and parking locations were equipped with Wi-Fi transceivers. Each motorpool vehicle was installed with Wi-Fi communications in lieu of cellular communication telematics. Additionally, specific Wi-Fi access points were installed strategically at motorpool locations. Each motorpool location required strategically placed Wi-Fi access points to provide sufficient Wi-Fi connectivity. The motorpool garage in District 4 (Figure 5.8) required a Wi-Fi access point and an additional Wi-Fi extender to provide suitable coverage.

The Wi-Fi communication architecture in District 7 underground parking garage was particularly challenging. The Wi-Fi connection to the Alt-Fuel Server is achieved at each location with a Wi-Fi cellular modem. The cellular modem transfers vehicle data from the motorpool parking area directly to the Alt-Fuel Server without passing through Caltrans intranet. The underground parking garage in District 7 does not receive adequate cellular signal. The cellular Wi-Fi modem was installed on the ground floor with an external Wi-Fi antennae cable routed two floors underground to the lower parking level. The directional Wi-Fi antennae was then mounted to the terminated end of the cable. This architecture allowed for vehicle data to be transmitted by Wi-Fi underground and then broadcast by cellular to the Alt-Fuel Server located at UC Riverside. Figure 5.9 shows the underground parking and directional Wi-Fi antennae coverage.

District 8 motorpool parking is located on the upper deck of the district parking garage and possesses sufficient cellular and Wi-Fi coverage as seen in Figure 5.10. District 11 motorpool parking is also located outdoors but is a significant distance from the building power supply. An additional solar powered Wi-Fi range extender was installed on the light pole in District 11 parking lot. The solar range extender was configured with a battery to allow several consecutive days of operation without sunlight. All four district locations utilized Wi-Fi to transmit motorpool vehicle activity and E85 fuel use.

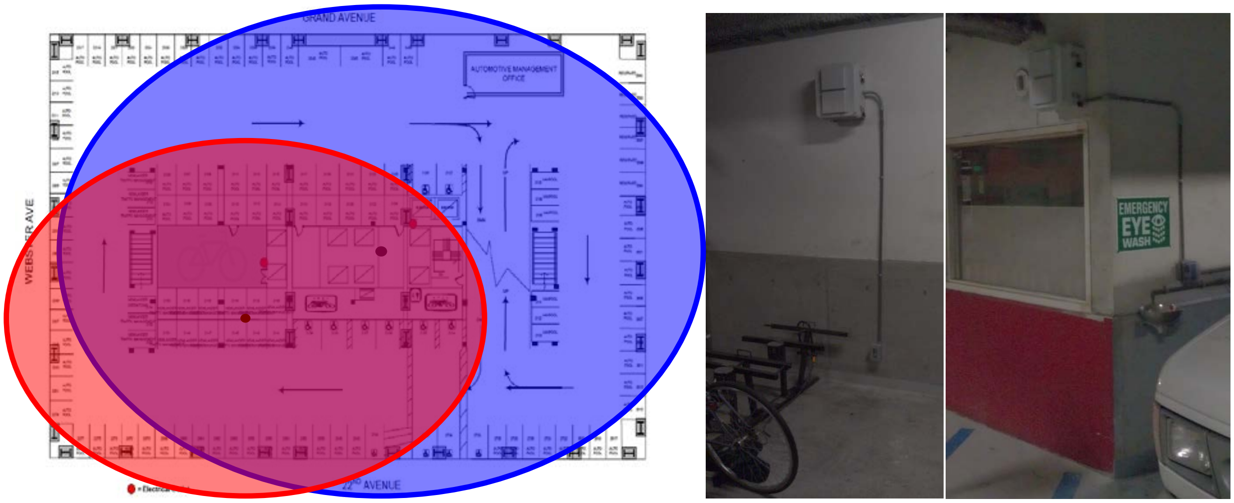


Figure 5.8. District 4 motorpool Wi-Fi installation.

Figure 5.9. District 7 motorpool Wi-Fi installation.

Figure 5.10. District 8 motorpool Wi-Fi installation.

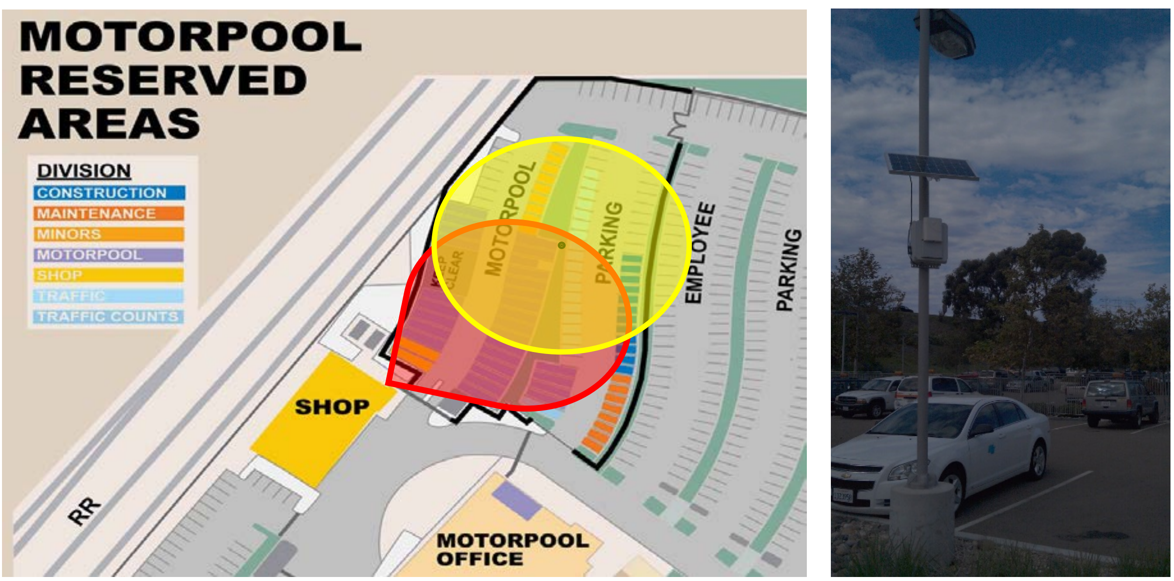


Figure 5.11. District 11 motorpool Wi-Fi installation.

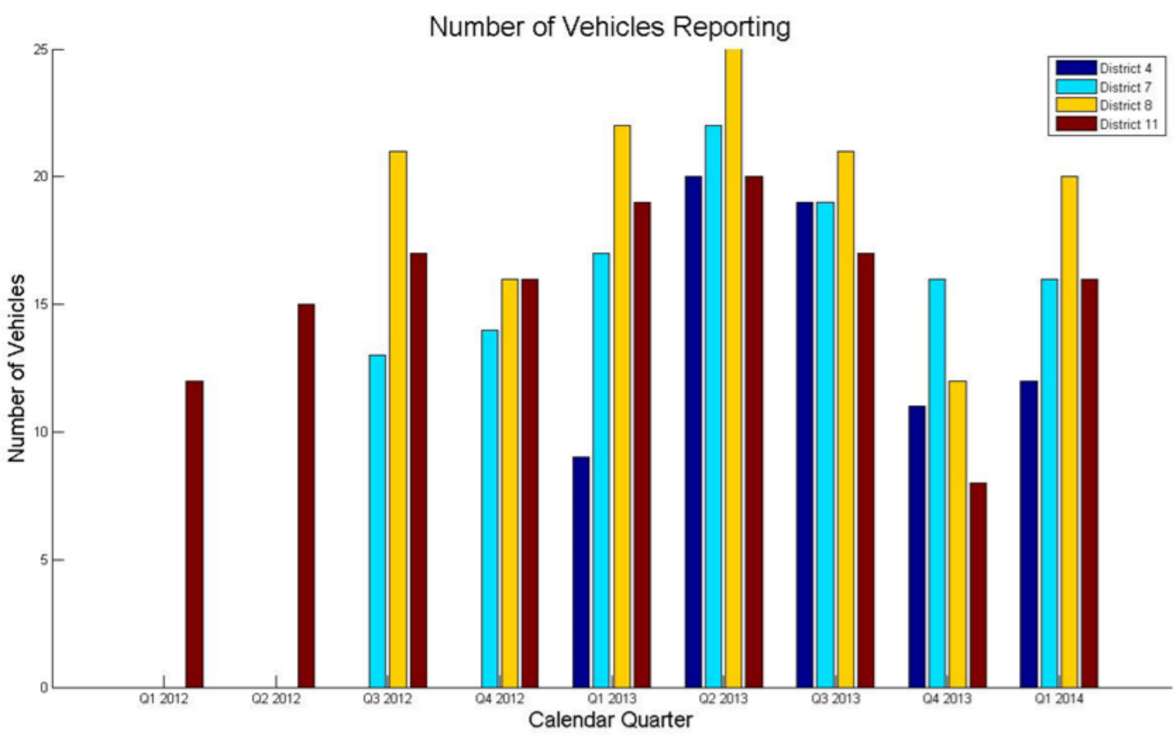
5.3 Vehicle Deployment and Operation

Upon installation and deployment, the vehicle data was transmitted to the server. During this time, the vehicles were used for various purposes during normal operations. Their fuel use, fuel mixture, refueling locations, and total quantity of fuel consumed were recorded in the database, and this database was accessible to Caltrans TAG personnel for evaluation. Training was provided to the personnel as necessary so that they understood how to best use the system. In addition, regular teleconference meetings were held with the TAG for feedback and interaction.

A total of 100 vehicles were equipped and operated with telematics across the four designated districts. During this period, the overall data and system status was analyzed to see if it provided the necessary functionality for monitoring the alternative fueled vehicle fleet.

During the operational period, several anomalies occurred with data collection. These anomalies have contributed to significant variation of data collected and some instances of unrecoverable data. Data collection variability and inconsistencies were presented during regularly scheduled TAG meetings. Numerous trips occurred to district locations to resolve individual vehicle telematic issues and/or Wi-Fi related disruptions. Figure 5.12 shows the status of vehicle reporting during the operational period.

Several possibilities can lead to reduced activity seen in Figure 5.12. Reduced activity in Figure 5.12 correlates with fewer recorded vehicle trips. The reduced activity is either attributed to less vehicle use or complete trip reporting failure. Data was not available to determine when a vehicle was completely idle and not operated versus not collecting data. The trip reporting failure can be vehicle specific or district specific. Data loss was experienced on both Wi-Fi equipped vehicles and cellular equipped vehicles. Problems originating from vehicle hardware were evenly distributed between all vehicles and all locations. However, failure in Wi-Fi infrastructure at the motorpool locations would disrupt all incoming Wi-Fi trip reporting. This type of failure occurred on at least two occasions and led to significant data loss of Wi-Fi equipped vehicles at Districts 4 and 7. In total, approximately twice as much data was lost from Wi-Fi equipped vehicles versus cellular equipped vehicles.



Calendar Quarter: Q1 (Jan – Mar), Q2 (Apr – Jun), Q3 (Jul – Sept), Q4 (Oct – Dec)

Figure 5.12. Quarterly status of data collection vehicles operating in system deployment.

The following conditions lead to lack of trip data. The first condition is when a vehicle is actually not operated at all during the period. The second condition would be a failure of the box to transmit trips via cellular communication during the identified period. The third condition is a failure of Wi-Fi communication during the identified period. Evaluation of data has revealed that the majority of inactivity for two weeks or less is primarily due to non-use of the vehicle. Periods of several weeks have been attributed to faulty hardware and/or communication disruptions.

The total number vehicles operating quarterly by district and successfully transmitting data are shown in Figure 5.12. District 11 was transmitting data several months prior to other districts due to continued participation from Phase II. Districts 4, 7, and 8 were newly recruited in Phase 3 and subsequently had a delayed deployment.

Since the system architecture, design, implementation, and operation was new to three districts the staff and TAG members, project specific training was organized for Districts 4, 7, and 8. Members from the CE-CERT development team travelled to the districts and presented the system operation and how to utilize the web interface. A User’s Guide was reviewed and distributed. The training session allowed potential users and TAG members to critique the user interface and provide feedback to the development team.

6. SYSTEM EVALUATION AND RESULTS

The deployment consisted of 100 vehicles, with Districts 4, 7, 8, and 11 each providing a minimum of 20 vehicles and staffing to coordinate with deployment and monitoring. During the operational period the following data was collected:

- 37,309 trips with second-by-second GPS location;
- 588,141 miles of OBD-II monitoring;
- 29,837 gallons of fuel consumed with refueling event locations; and,
- 19.7 mpg average fuel economy.

Extensive data analysis was completed to better understand the vehicle activity, fuel use, and observable trends. The fuel use shown in Figure 6.1 details a greater amount of fuel use during the middle of the system deployment. Further analysis of vehicle activity and data reporting explains this trend being related to vehicle activity and refueling behavior. Figure 6.2 displays weekly trip totals and agrees with the fuel use trend seen in Figure 6.1. This data analysis has been summarized in the following graphs and figures.

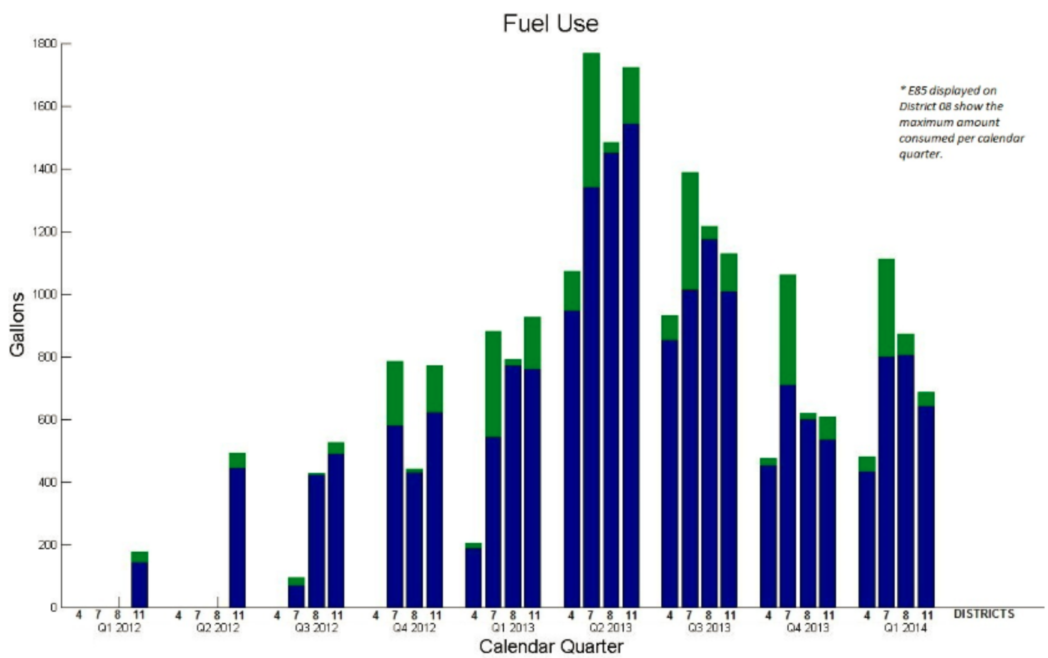


Figure 6.1. Quarterly status of fuel consumption with unleaded (blue) and E85 (green).

To help clarify the fueling variability seen in Figure 6.1, the number of trips and miles travelled were evaluated for each quarter. Figure 6.2 shows the number of trips completed during the system deployment while Figure 6.3 displays the fuel economy achieved by district during each quarter. Figure 6.3 provides 5% error bars showing significant variability due to vehicles and drivers. Evaluation of the three graphs indicates a greater amount of vehicle activity captured during the beginning of 2013. Less vehicle activity was recorded in the beginning and end quarters of the study. This information will be combined with further analysis to determine overall E85 fuel trends.

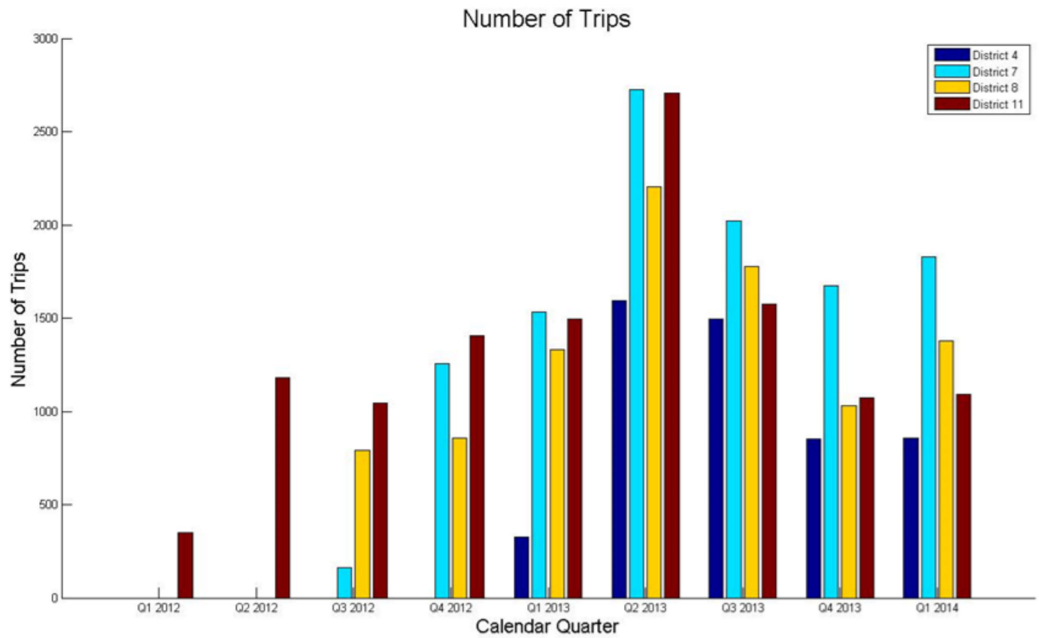


Figure 6.2. Quarterly number of trips during the system deployment.

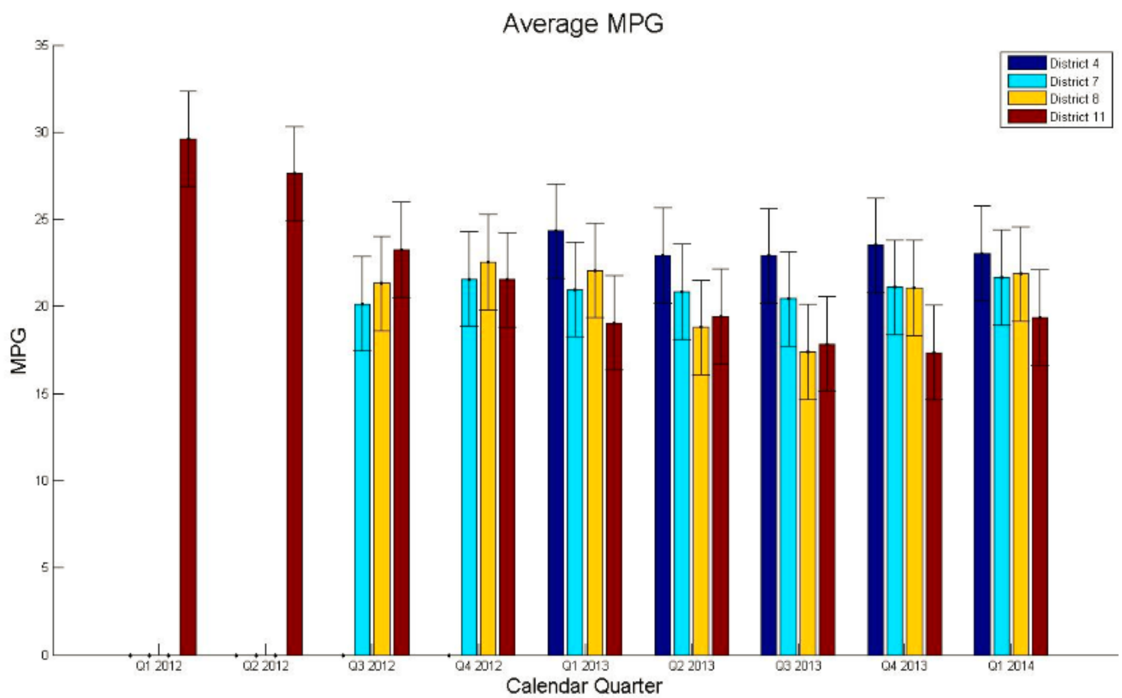


Figure 6.3. Fuel economy by district for the deployment period.

6.1 Vehicle Activity Analysis

Analysis was completed to determine if regional characteristics influence vehicle activity and fuel use characteristics. This analysis focused on fuel use, number of trips, miles travelled and quantity of vehicles reporting. The similarities and differences between the districts are presented below. Figure 6.4 presents the number of vehicles reporting data each month within each district. Each district had maximum reporting during the Spring of 2013. District 8 had the greatest quantity of vehicles reporting due to over 30 vehicles being equipped. District 11 had the most consistent and stable quantity of vehicles reporting with 16 to 18 vehicles reporting most months. District 7 had a large quantity of vehicles reporting until June 2013 with a significant reduction due to the motorpool cellular modem failure. District 4 was the last district to deploy with 20 vehicles total. District 4 had a maximum of 16 vehicles reporting in June and July of 2013.

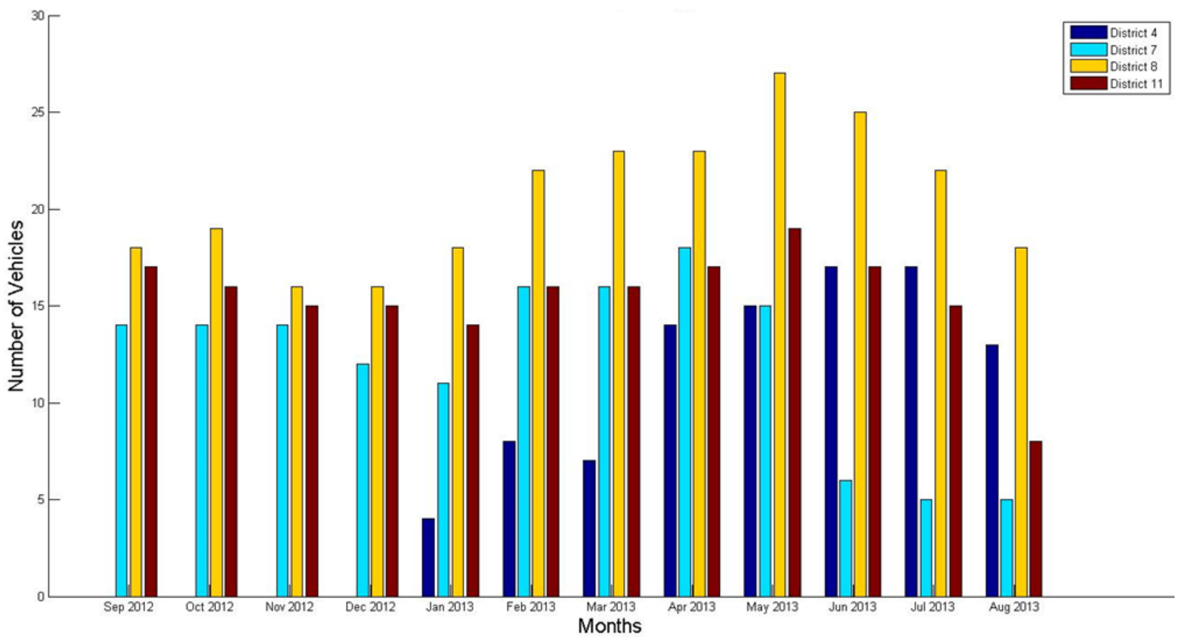


Figure 6.4. Monthly number of vehicles reporting by district.

Figure 6.6 details the proportion of cellular equipped vehicles reporting versus Wi-Fi equipped vehicles reporting. The Wi-Fi equipped vehicles are motorpool vehicles and commonly sedans. The cellular equipped vehicles are generally department assigned vehicles and are comprised of trucks, sedans, and vans. The reduction in Wi-Fi reporting during the final three months in District 7 becomes apparent in Figure 6.6.

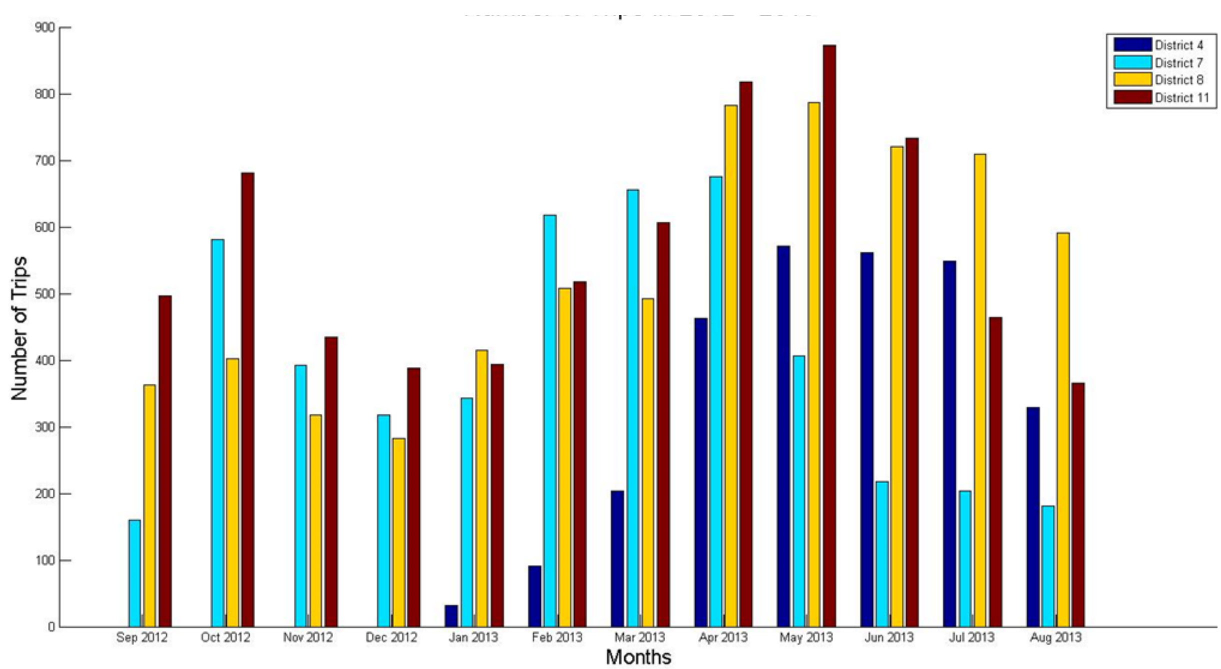


Figure 6.5. Monthly number of trips reporting by district.

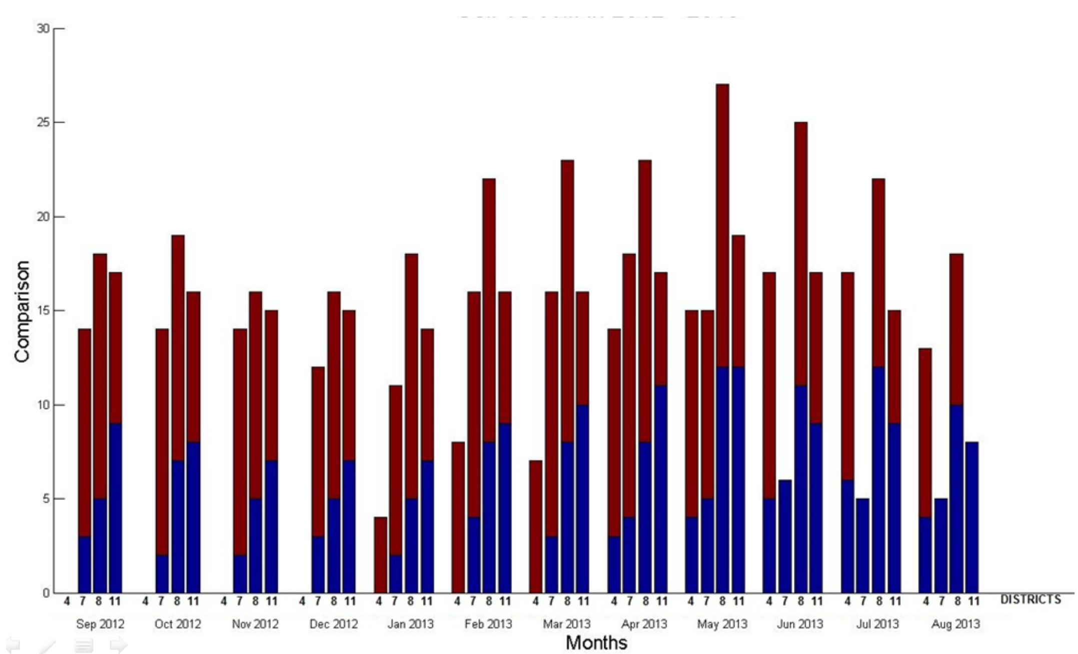


Figure 6.6. Monthly cellular (blue) versus Wi-Fi (red) reporting during the system deployment.

6.2 District Refueling Analysis

Each district location has a unique spatial geographic distribution of refueling stations in proximity to the district office motorpool location. Refueling events were segregated into E85 refueling events and unleaded refueling event. Some district locations have limited E85 refueling infrastructure while other locations have numerous options. Figure 6.7 provides the E85 refueling locations for District 4 and the proportion of refueling events occurring at the prominent locations. Figure 6.7 shows half of the E85 refueling events occurring at the district operated refueling yard. Figure 6.8 shows only 28% of unleaded refueling events occurring in close proximity to the district office.

Figures 6.9 and 6.10 show the refueling trends for District 7. Nearly 90% of E85 refueling at District 7 occurs at the Caltrans managed fuel terminal. Whereas, only about 20% of the unleaded refueling occurs in close proximity to the District 7 office (Figure 6.10). District 8 shows two thirds of refueling events taking place at the district refueling facility (Figure 6.11). The remainder of E85 refueling for District 8 is in Corona. The unleaded refueling for District 8 shows approximately 40% at a local public station as seen in Figure 6.12.

Figure 6.13 and 6.14 show the geographic refueling trends for District 11. Nearly 90% of E85 occurs at a single station close to the district office while less than 20% of unleaded refueling occurs in close proximity to the district office. The refueling trends are likely the result of numerous factors. The employees and drivers of the vehicles are most familiar with E85 refueling locations in close proximity to the district offices. The E85 refueling locations in close proximity to the district office are owned and operated by Caltrans. Refueling events occurring distant to the district offices are more likely to be unleaded due to the limited availability of E85 refueling.

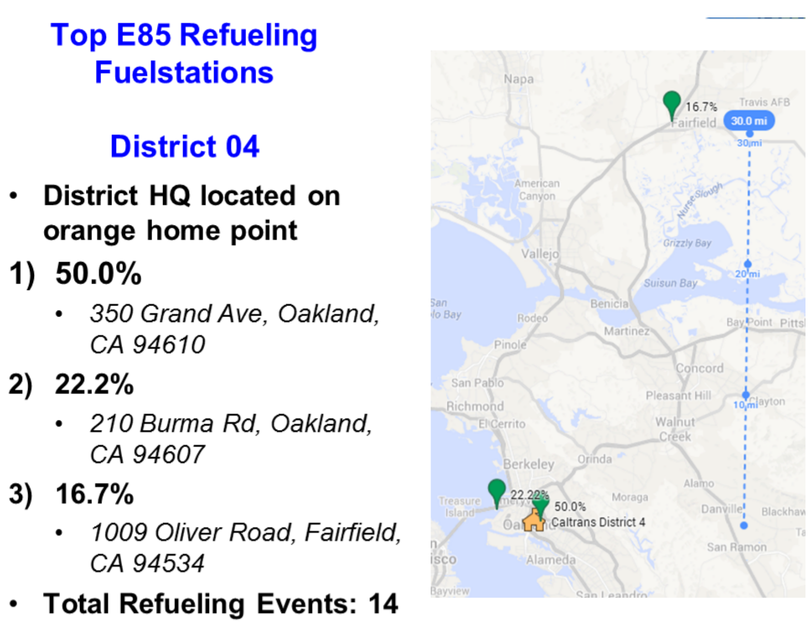


Figure 6.7. District 4 primary E85 refueling locations.

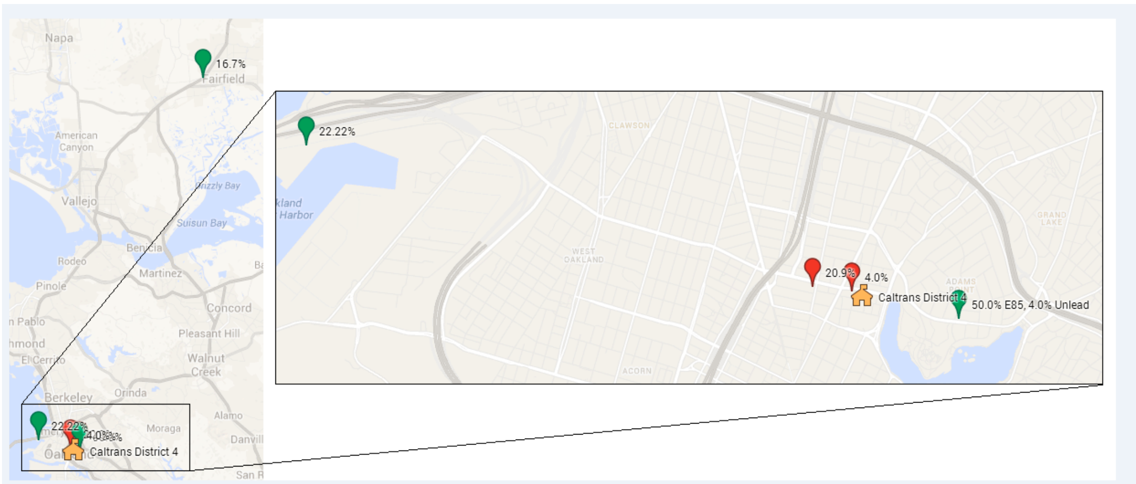


Figure 6.8. District 4 E85 and unleaded refueling location comparison.

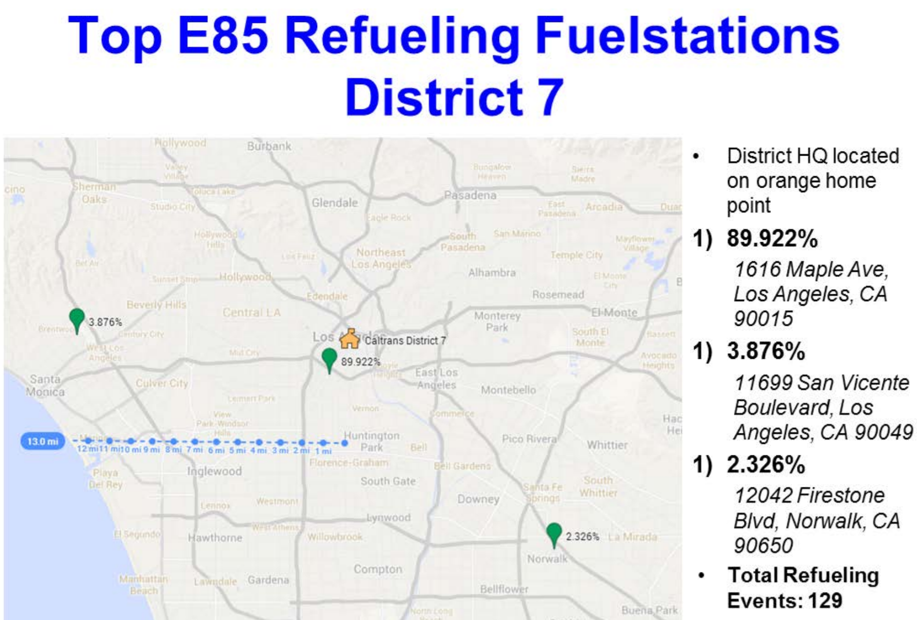


Figure 6.9. District 7 primary E85 refueling locations.

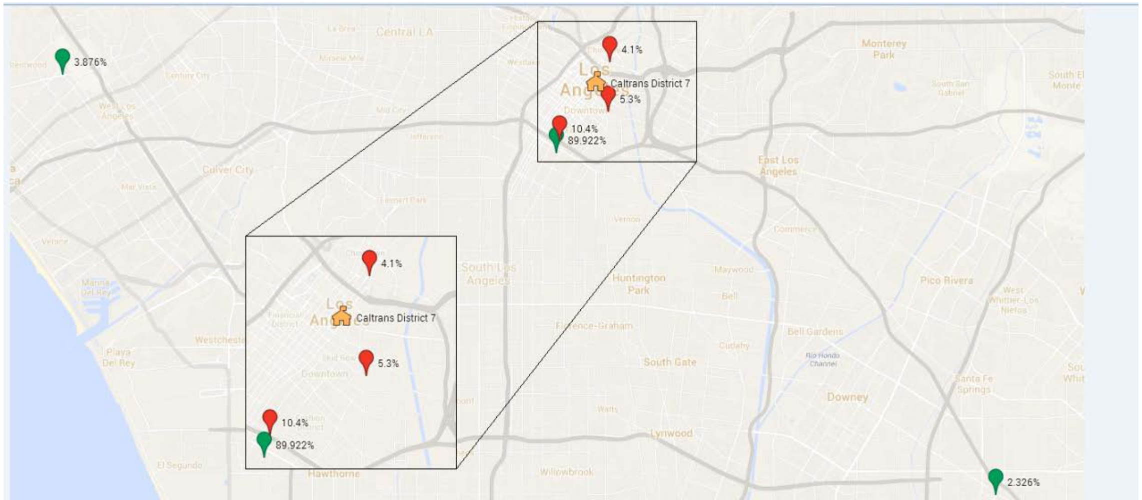


Figure 6.10. District 7 E85 and unleaded refueling location comparison.

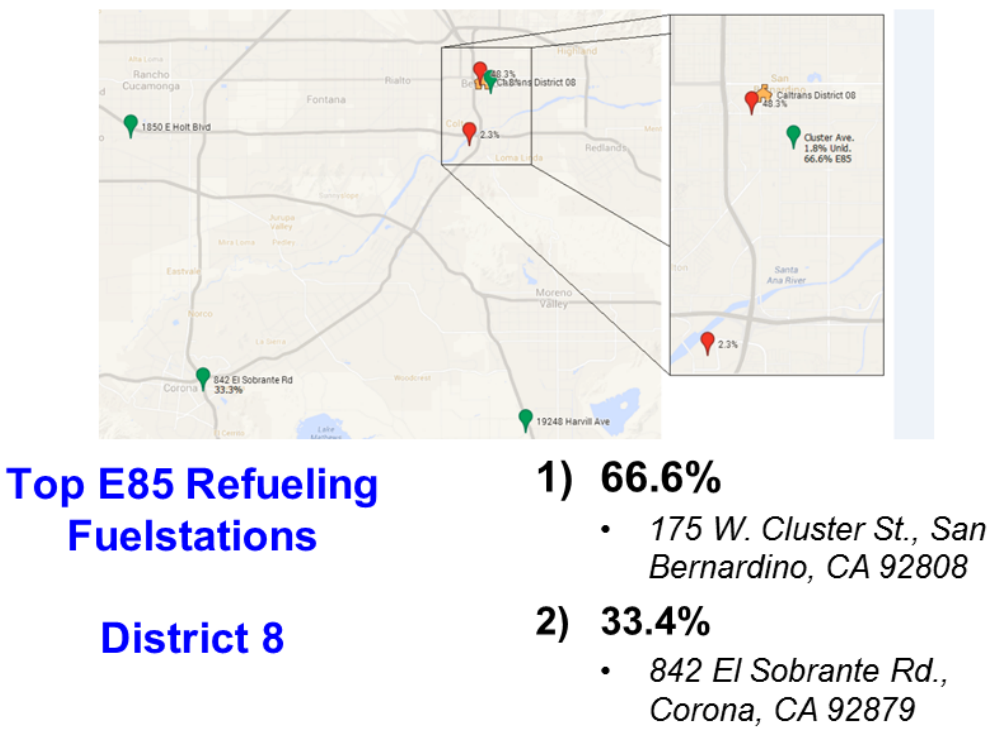


Figure 6.11. District 8 primary E85 refueling locations.

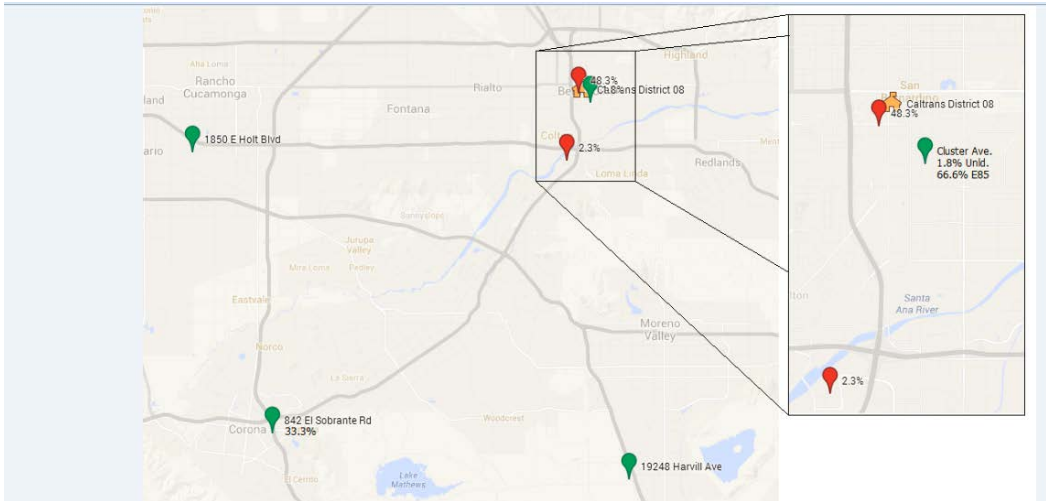


Figure 6.12. District 8 E85 and unleaded refueling location comparison.

Top E85 Refueling Fuelstations

District 11

- District HQ located on orange home point

1) **83.72%**
   - *4067 El Cajon Blvd, San Diego, CA 92105*
2) **6.98%**
   - *2741 Gateway Road, Carlsbad, CA 92009*
3) **4.65%**
   - *7181 Opportunity Rd, San Diego, CA 92111*

- **Total Refueling Events: 43**

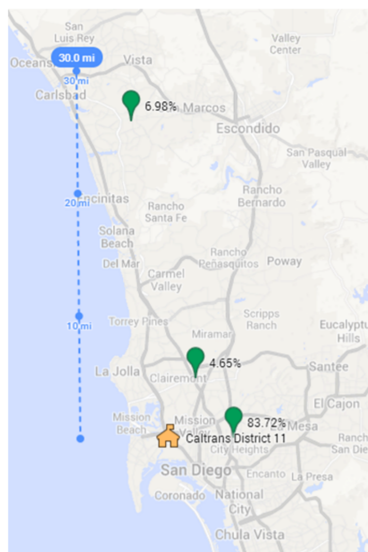


Figure 6.13. District 11 primary E85 refueling locations.

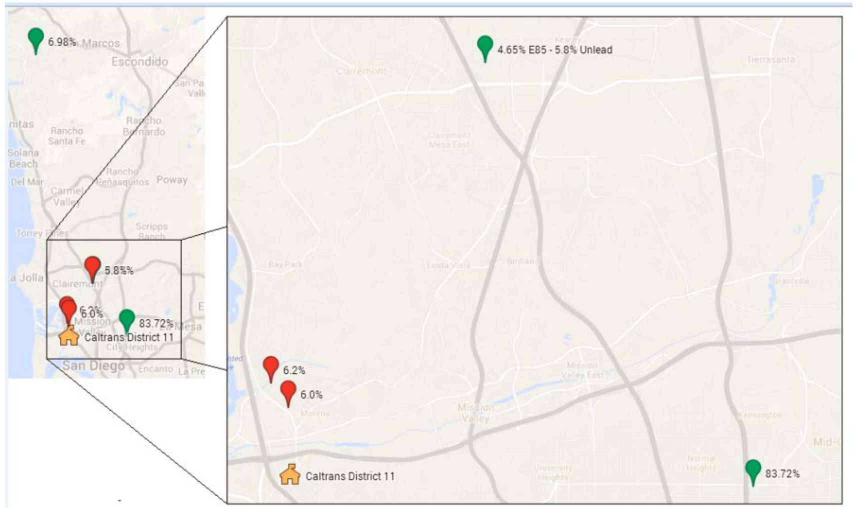


Figure 6.14. District 11 E85 and unleaded refueling location comparison.

6.3 Vehicle Activity Data and Fuel Use by Vehicle Type

Since several different vehicle models were incorporated into the deployment system, analysis by vehicle type has been completed. The analysis includes:

- Trip distance;
- Trip duration;
- Fuel economy; and,
- Fuel composition.

The vehicle composition for sedans consists of Chevrolet Impalas and Malibus. The trucks integrated within the system are comprised of Chevrolet Silverados and Uplanders. The trip distance histogram for sedans and trucks is shown in Figures 6.15 and 6.16 respectively. Approximately half of the sedans in each district are travelling less than 20 miles per trip. All trips over 50 miles are grouped collectively and comprise of approximately 5% of the trips. The trucks are shown to have the great majority of trips below 25 miles. It should be noted that Districts 4 and 7 have minimal truck activity due to primarily equipping motorpool sedans. District 4 has two Uplanders equipped while District 7 has a single Silverado. Districts 8 and 11 have approximately 2% of the truck trips over 50 miles.

Figure 6.17 displays a trip time histogram for sedans. The histogram shows that nearly all trips are over 5 minutes with nearly half of the trips between 5 minutes and 25 minutes. Approximately 20% of the sedan trips are over 50 minutes. The truck time histogram shows nearly 90% of truck trips less than 30 minutes (Figure 6.18).

Figure 6.19 and 6.20 present the fuel economy histograms for sedans and trucks, respectively. The sedans have a broad distribution of 10-35mpg while the trucks have a more narrow range of

10-20mpg. The broad range of the sedans is partially due to the mixed vehicle composition of smaller engine Malibus and larger engine Impalas.

Fuel composition histograms were completed for sedans (Figure 6.21) and trucks (Figure 6.22) for each district. The sedan fuel composition histogram shows increased prevalence of low E85 percentages with diminishing frequency between 30% E85 and 70% E85. The proportion begins to increase again as fuel composition approaches 70%. The fuel composition for trucks displays the vast majority of fuel composition either below 20% E85 or over 80% E85. The truck fuel composition trend seems to indicate that the truck refueling has sequential E85 refueling events followed by sequential unleaded refueling events. Conversely, the sedan refueling histogram is more indicative of alternating between unleaded and E85.

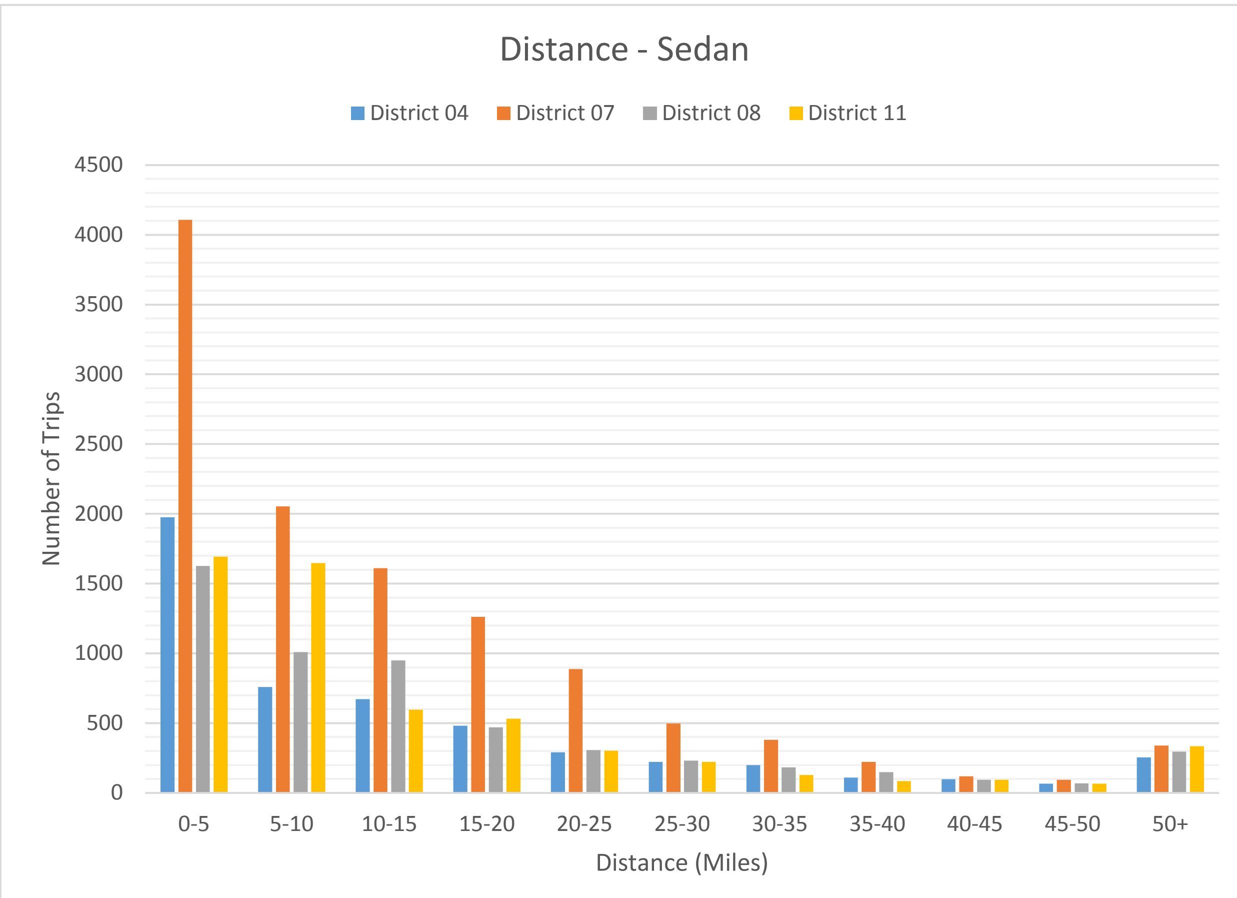


Figure 6.15. Trip distance histogram for sedans operating in the deployment program.

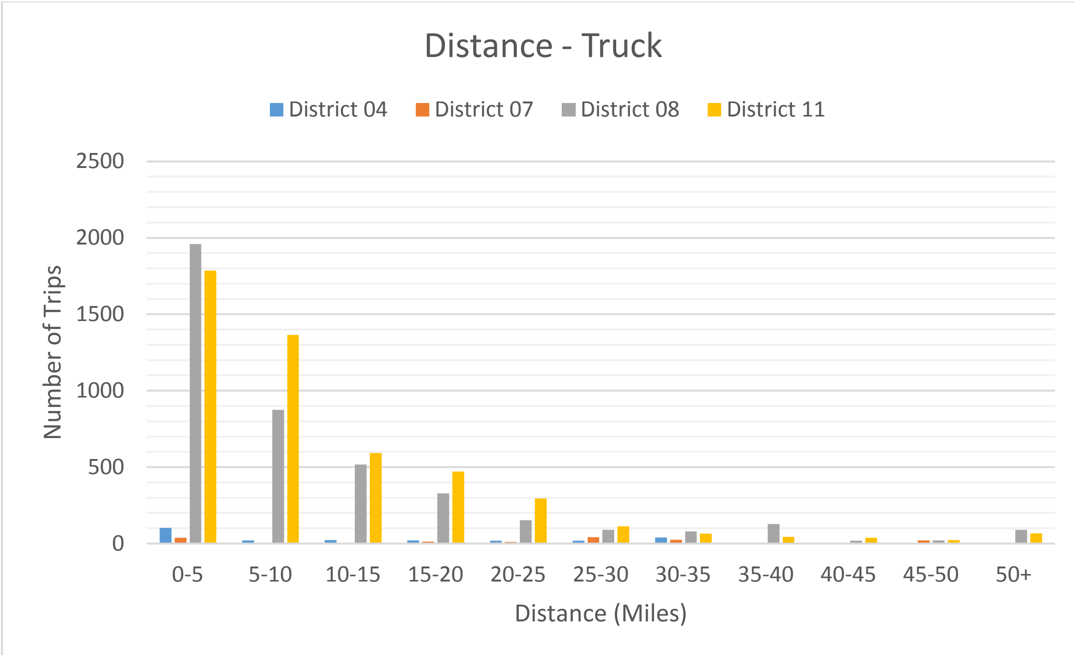


Figure 6.16. Trip distance for trucks operating in the deployment program.

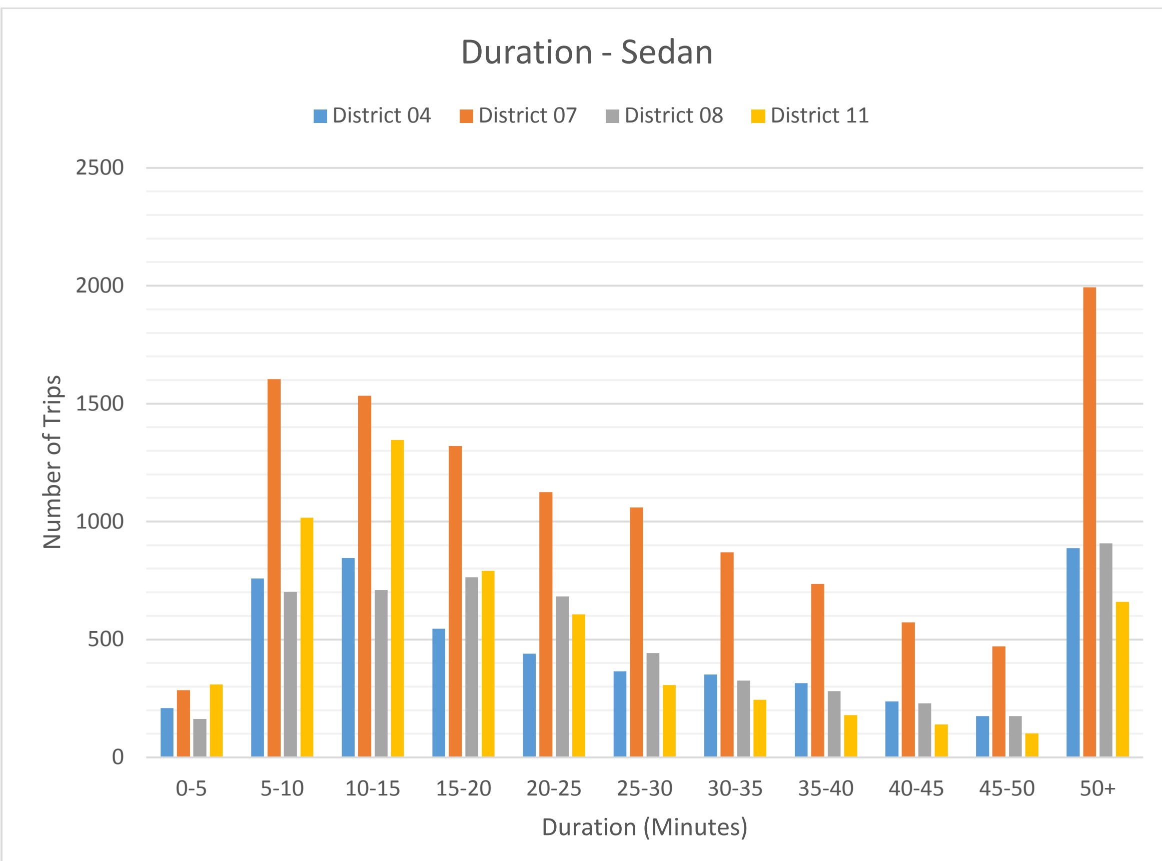


Figure 6.17. Trip time duration histogram for sedans operating in the demonstration program.

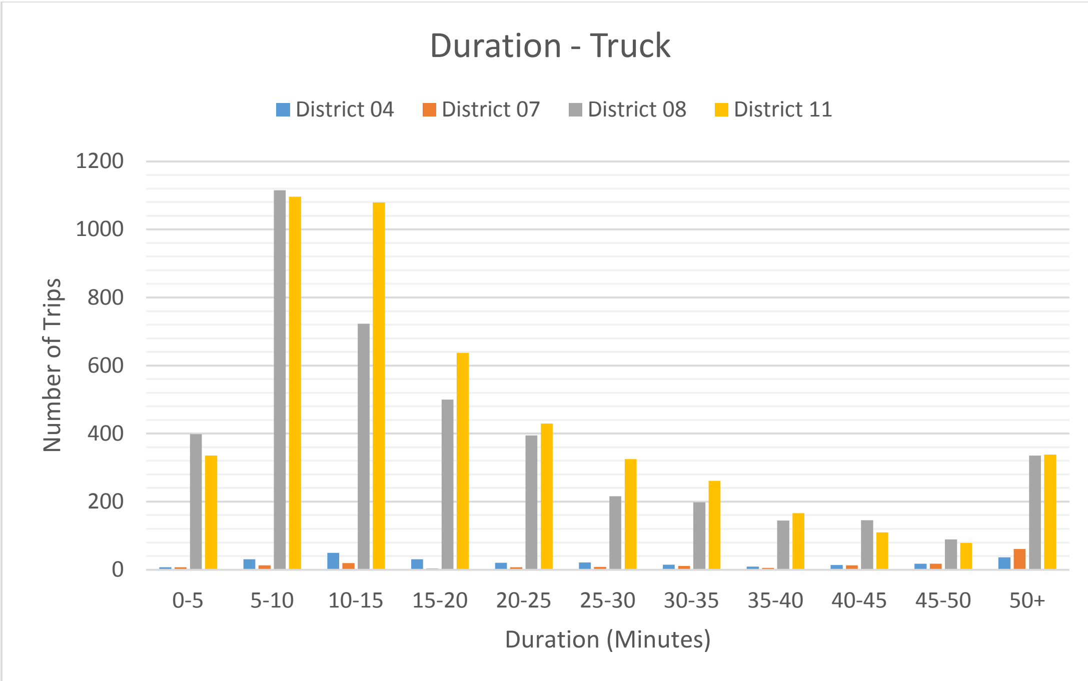


Figure 6.18. Trip time duration histogram for trucks operating in the demonstration program.

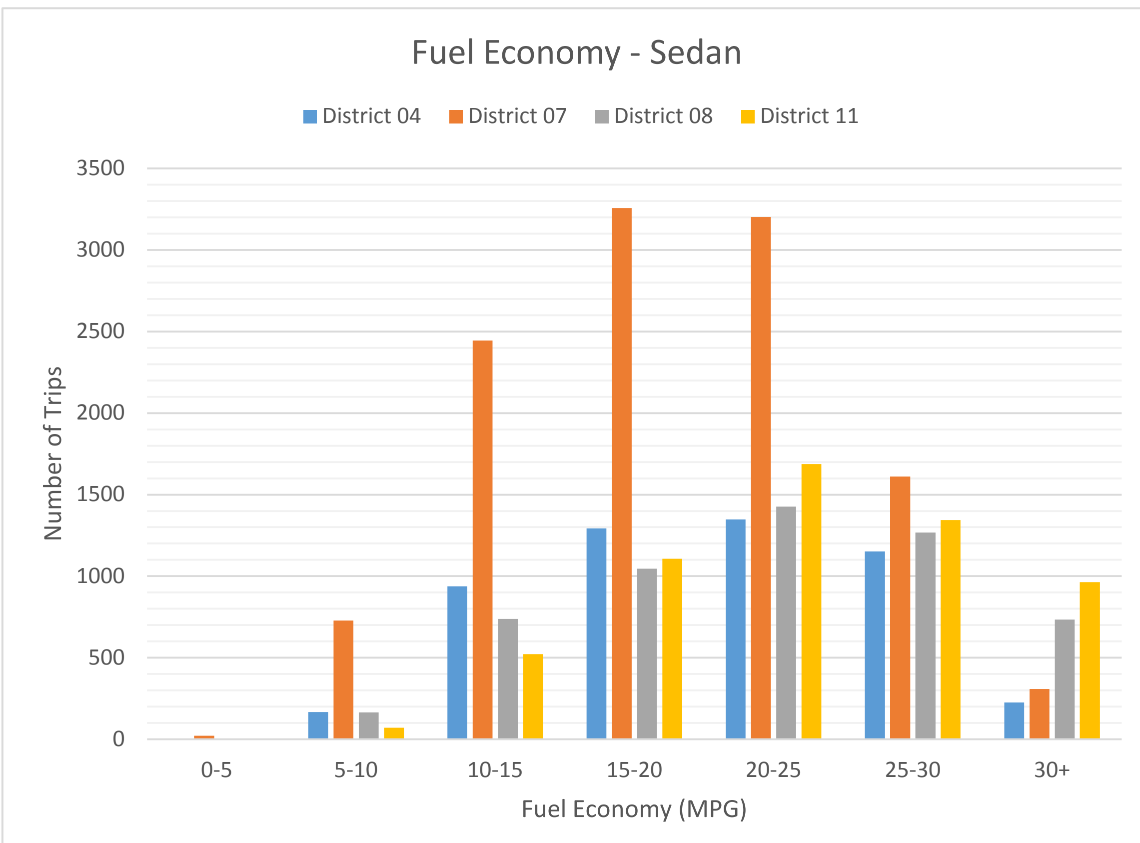


Figure 6.19. Fuel economy histogram for sedans operating in the demonstration program.

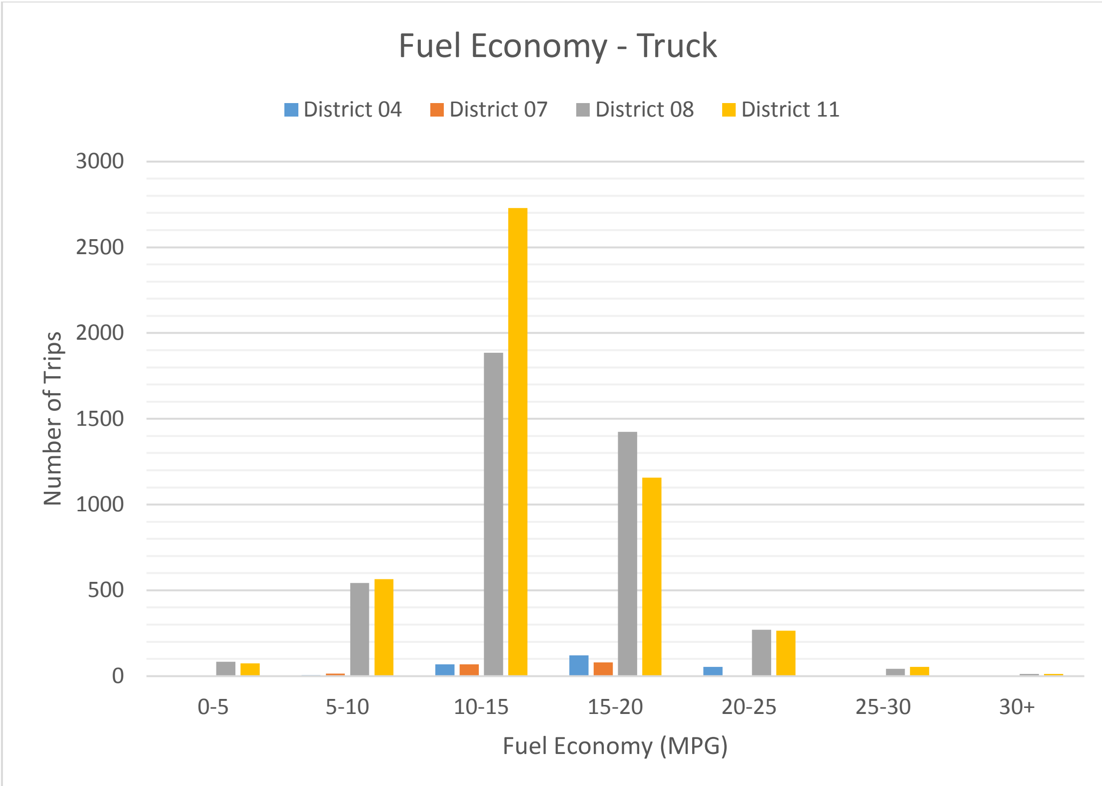


Figure 6.20. Fuel economy histogram for trucks operating in the demonstration program.

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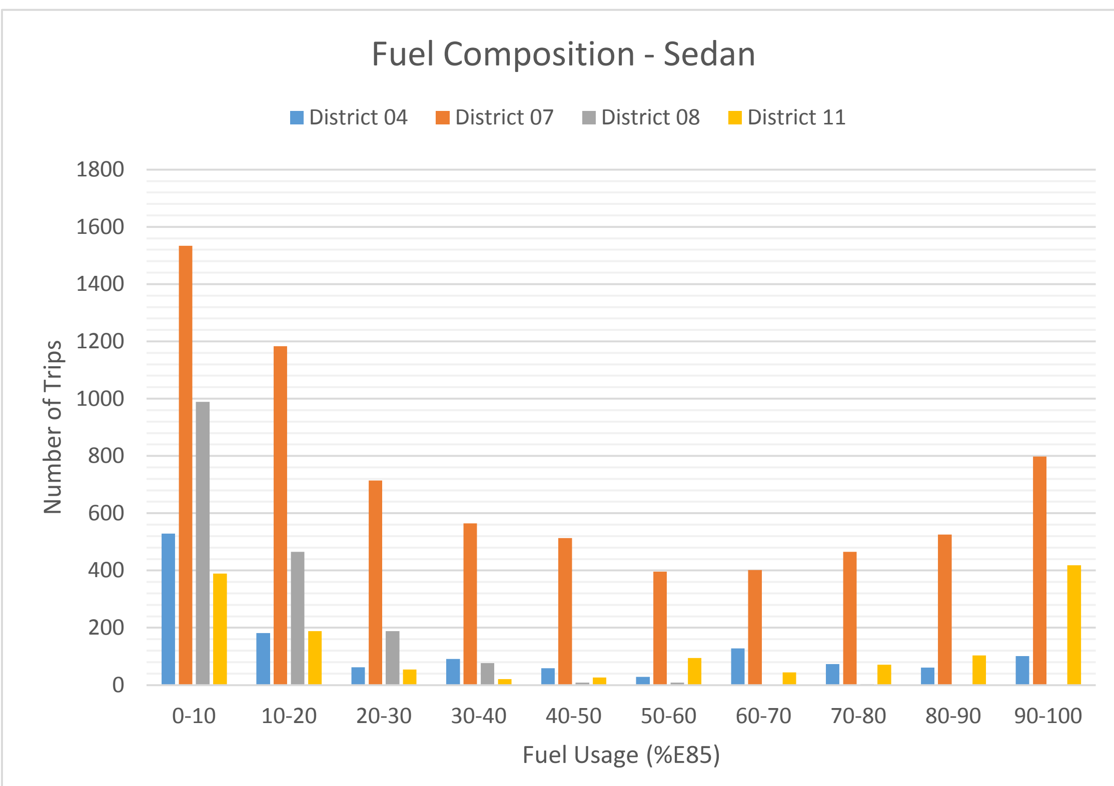

Figure 6.21. Fuel composition histogram for sedans operating in the demonstration program.

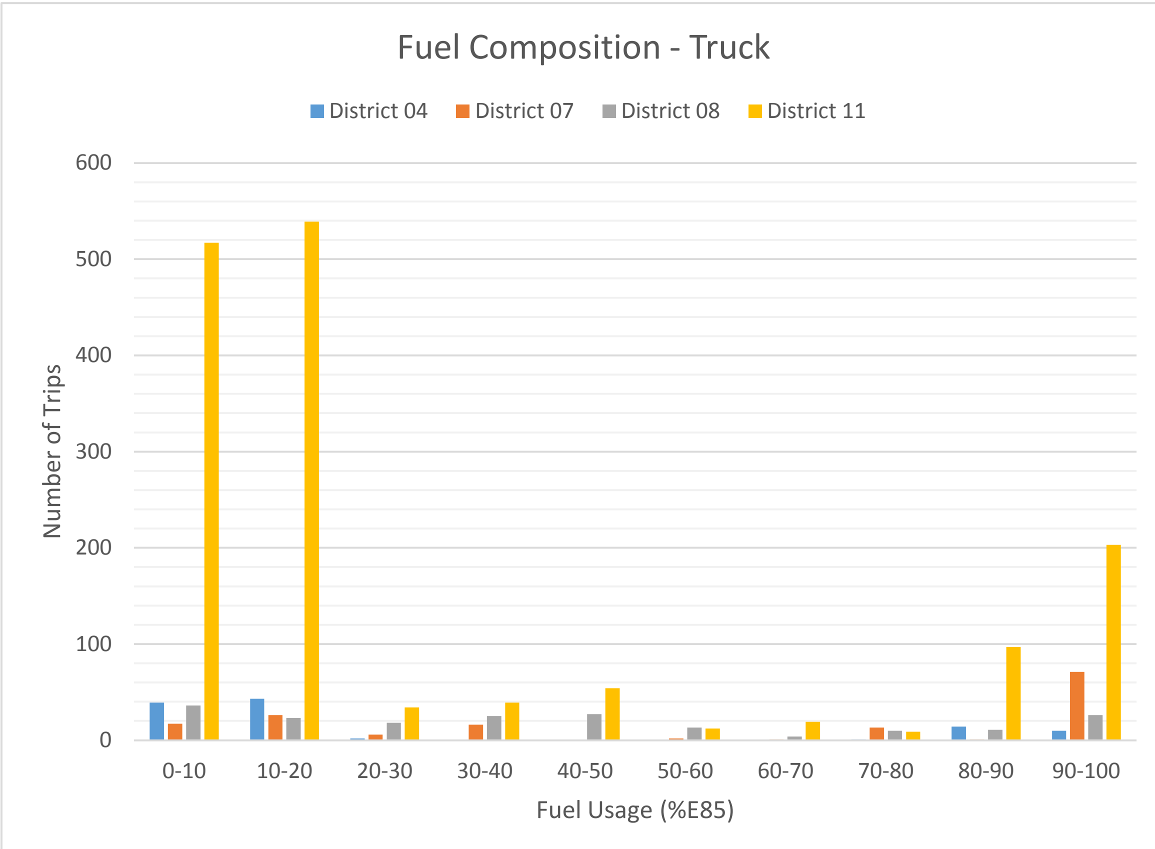

Figure 6.22. Fuel composition histogram for trucks operating in the demonstration program.

7. DEPLOYMENT PLAN ARCHITECTURE

Based upon the results of all three Phases of work a deployment plan has been developed for extending the monitoring system to many additional flex-fueled and bi-fueled vehicles within the Caltrans' fleet, across the state. The full deployment plan is provided in Appendix B. It is expected that the individual cost on a per vehicle basis will decrease once the hardware and software have been refined and mass produced. Vendors will be approached to provide the vehicle on-board hardware at a reasonable cost. There is little change expected to occur with the system server hardware, since the server is currently able to handle thousands of vehicles simultaneously.

The deployment plan has been developed in conjunction and coordination with both the DRISI deployment branch and the project manager. In addition to the deployment architecture being described below, there is a standalone deployment plan attached as Appendix B.

7.1 Proposed System Architecture

To fully achieve these goals with a technology implementation that is non-proprietary and non-vendor specific, a modular architecture is being proposed. This modular approach consists of three modules with specific communication protocols to be defined by this proposed work. The modular approach allows the system components to be agnostic to any other module. The diagram below (Figure 7.1) provides highlights the three major components of the system.

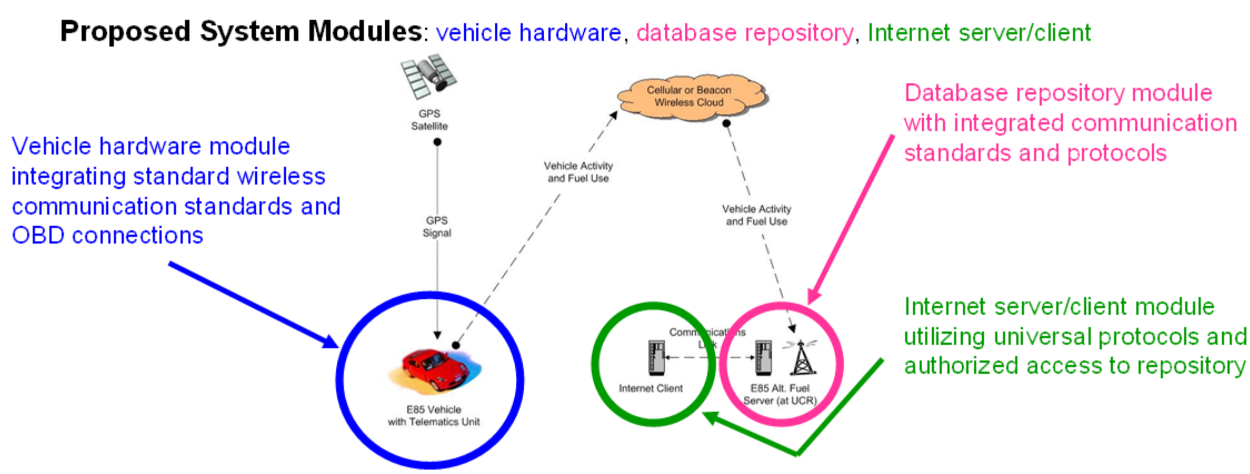

Figure 7.1. Proposed architecture for future deployment.

The primary goal of the modular design is to allow the system to be expandable and agnostic to a specific creator/vendor. For example, a hardware vendor could produce the vehicle side hardware. A second vendor could be used to produce the Web Server/Client interface and finally a third vendor could be contracted to support the Database Repository Module. This approach of open design provides the end user with a very cost effective and maintainable solution. The modular design also ensures that the future support and growth of the system will not be dependent on a sole vendor to provide the solution.

Figure 7.2 below depicts the flow of data from the vehicle to the end user. The diagram provides a map of the data flow and all the services/programs that are required to display/generate the web based interface/reports. There are three major modules of the design as shown below:

- Vehicle Hardware Module (VHM) – Consisting of on-board telematics hardware/firmware;
- Data Repository Module (DRM) – Comprising the hardware and software required to process and manage the database; and,
- Web Client Interface (WCI) – Interface and data mangagement components to share and present database information.

The flow of data between the modules requires specific communication protocols and formats. The goal of this deployment is to create a open standard that can be utilized and adopted by the telematics industry for the mantenance of vehicle activity databases.

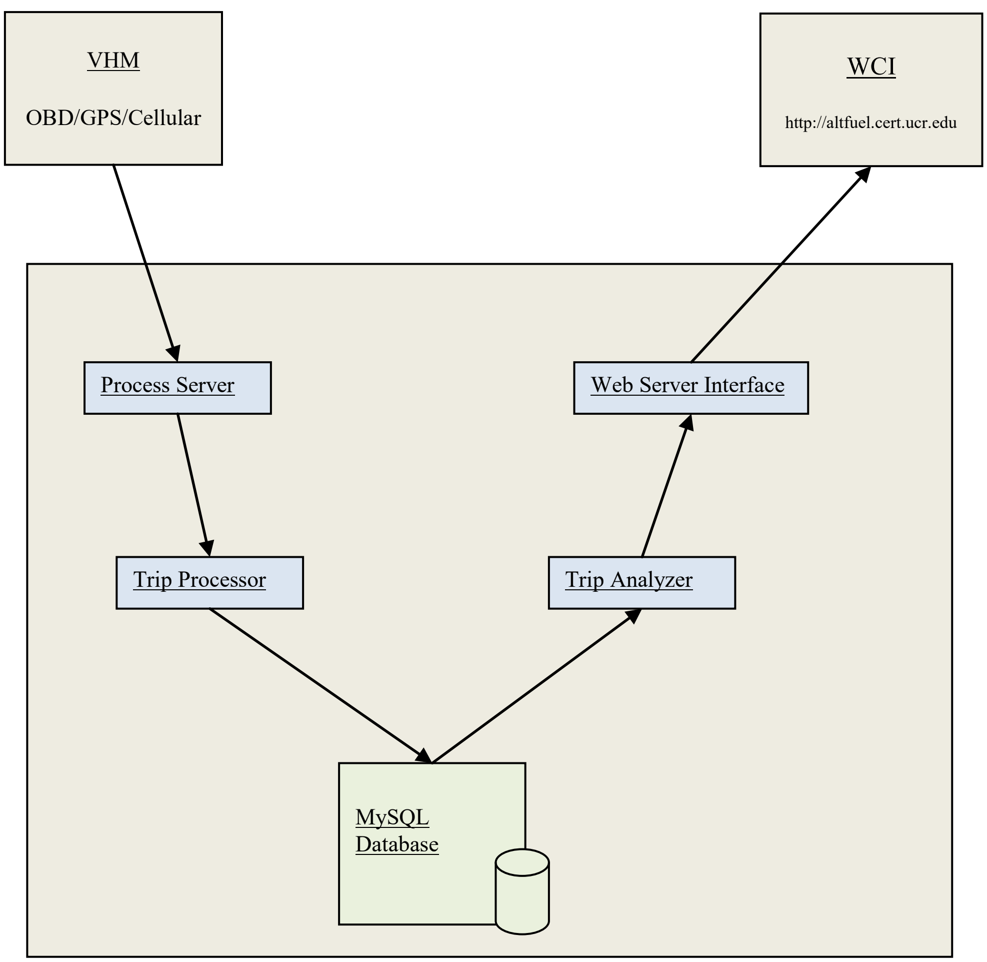

Figure 7.2. Server data flow diagram for telematics and web client programs.

8. CONCLUSIONS AND FUTURE WORK

Over time, Caltrans has invested in a variety of alternative fueled vehicles as part of its in-use vehicle fleet. By using alternative fueled vehicles that run on ethanol, compressed natural gas (CNG), propane, or bio-diesel, there should be a quantitative improvement in CO_2 emissions, better fuel economy, and general support for energy independence. However, it has been very difficult to determine how much these vehicles are actually using alternative fuels, especially when the vehicles have bi-fuel capability.

This project has developed, deployed, and evaluated a system that can monitor alternative fuel usage in the Caltrans fleet, and provide a means for managers and supervisors to access these data in a meaningful way. The developed system includes on-board monitoring hardware that has telematics capabilities of sending this information to a system server that can be readily accessed via the Internet. The developed system has integrated commercially available on-board vehicle telematics from viable domestic vendors.

This report has detailed the integration and deployment of a commercial E85 alternative fuel monitoring system. This report has highlighted the following characteristics:

- Integration of vendor supplied on-board vehicle telematics comprising the Vehicle Hardware Module (VHM) – this on-board hardware module is responsible for gathering vehicle activity data and transmitting data to the database by either cellular or Wi-Fi.

- Development and implementation of a database and web server interface – these applications provide a method for Caltrans staff to review vehicle activity and fuel information.

- System integration and deployment – over a year of four district operational data required for a thorough evaluation.

- Evaluation and analysis of results – over 37,000 trips were evaluated relative to vehicle activity and fuel use trends.

- Deployment plan – documentation of system characteristics and commercialization steps have been discussed and outlined.

During the extended Phase III E85 Alternative Fuel Monitoring project, the following data was collected:

- 37,309 trips with second-by-second GPS location;

- 588,141 miles of OBD-II monitoring;

- 29,837 gallons of fuel consumed with refueling event locations; and,

- 19.7 mpg average fuel economy.

The data evaluation completed for this report has highlighted the vehicle activity and fuel use data necessary to understand E85 alternative fuel use trends. The system is a valuable tool when transitioning a fleet to alternative fuels requiring user behavior modifications. The monitoring system provides detailed vehicle activity and fuel consumption for every trip of an equipped vehicle. The information provided in this report and the details in the deployment plan are intended to smooth the transition to an alternative fueled vehicle fleet.

Numerous conclusions have been drawn from the technology implementation, system deployment, operation, data analysis, and results presented in this report. The conclusions from the technology implementation and system operation provide insight for areas of attention in future deployments. These areas include:

- OBD-II data inconsistencies require on-board hardware/firmware testing of each new model and model year of vehicle;
- A need exists for improved standards across multiple vehicle platforms (light duty and heavy duty) and encompassing expanded data variables (fuel composition, location, odometer etc.);
- 85 percent is a maximum threshold of ethanol for E85 with actual observed percentages being closer to 75 percent;
- Cellular and Wi-Fi communications are an effective and reliable means of wireless data transfer with Wi-Fi having lower operating costs but higher initial costs;
- Cellular proved to provide more reliable and consistent data transfer with Wi-Fi data loss being approximately two times the frequency of cellular data loss;
- On-board data storage should be carefully evaluated to insure against data-loss; and
- Once tested and proven on a specific model, the OBD-II connector is the ideal interface to connect fuel monitoring on-board hardware.

The extensive analysis of vehicle activity and fuel use has provided insight for targeted analysis in future evaluations. These data analysis conclusions and areas of interest include:

- Further analysis of individual vehicle activity which shows significant refueling variability depending on region of geographic vehicle operation;
- Familiarity with refueling locations is required for consistent E85 refueling;
- New telematics standards should be explored and evaluated (e.g. AEM/AEMP standard);
- Vehicle activity observations, such as trip distance, that effect fuel choice should be further explored to determine significance and frequency of occurrence;
- GPS aided navigation for refueling can potentially guide drivers to E85 refueling locations when operating in unfamiliar regions.

This implementation, demonstration, and analysis have provided a foundation for a future deployment of a commercial scale system. The future system should build upon the strengths of the deployed system while adding attributes. A key attribute is the modular open architecture presented in the Deployment Plan (Appendix B). This architecture creates a framework for future advanced fuel/energy monitoring and affiliated ITS applications. Additionally, improved on-board functionality could assist drivers in knowing current fuel composition, E85 refueling location, and fuel savings. Finally, enhanced web-based applications can assist staff, managers, and fleet operators in characterizing vehicle activity and quantifying fuel use.

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APPENDIX A: CALTRANS FACT SHEET

FACT SHEET

Caltrans

Research, Development and Evaluation of an E85 Alternative Fuel Fleet Monitoring System.

Why We Are Pursuing This Research

Over time, the California Department of Transportation (CALTRANS) has invested in a variety of alternative fueled vehicles as part of its in-use vehicle fleet. These purchases are required by state and federal mandate. It is very difficult to determine how much these vehicles are actually using alternative fuels, especially when the vehicles have bi-fuel capability (i.e., can run on gasoline or ethanol, gasoline or propane, gasoline or CNG, etc.).

What We Are Doing

This project initially developed, implemented, and evaluated a prototype system that can monitor alternative fuel usage in the Caltrans Ethanol 85 (E85) fleet, and provide a means for managers and supervisors to access these data in a meaningful way. The developed system includes on-board *monitoring hardware that has telematics capabilities of sending this information to a system server that is readily accessed via the Internet.*

Monitoring E85 fuel usage to help quantify fuel usage patterns within the vehicle fleet has previously proven to be a challenge. Traditional methods of matching E85 refueling records with vehicle identity have provided little insight with regards to vehicle activity of specific vehicles. To promote a more thorough understanding of alternative fueled vehicle activity in regards to fuel use, a specialized telematics system has been developed and implemented. This telematics system is shown in Figure 1 and consists of an onboard telematics device which collects real time sensor parameters from the vehicles OBD-II (On Board Diagnostics) port. Once a trip has started the system logs the real-time engine data along with the vehicles GPS position. Upon conclusion of a trip the information is and transferred to a server at UC Riverside via WiFi or a GSM/GPRS cellular connection. The associated system components include:

- *GPS vehicle positioning using satellite broadcasts;*
- *Vehicle telematic units interfaced with the vehicle OBD-II data bus;*
- *WiFi and cellular data communications for transmission of vehicle activity and fuel consumption data;*
- *Data repository and server for receiving and storing transmitted data; and*
- *Web-based user interface for reviewing previous vehicle activity and fuel consumption data.*

The system architecture was specifically designed to collect fuel composition data simultaneously with vehicle activity (location, miles travelled, speed etc.). This architecture was developed and tested with a single vehicle at UC Riverside prior the phase one pilot of ten (10) vehicles, five in District 3 and five in District 11. During the 6 months of the pilot program the following data were collected:

- *3965 trips with GPS location;*
- *58,200 miles of OBD-II monitoring;*
- 3,514 gallons of fuel consumed with refueling event locations (47 % E85); and,
- 16.7 mpg average fuel economy.

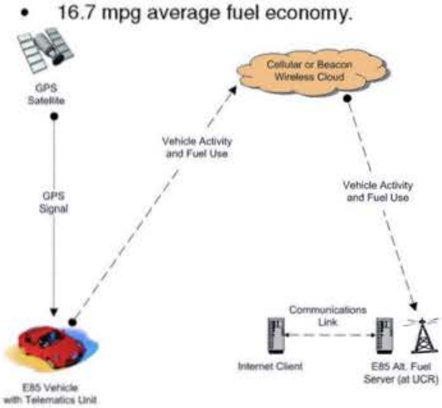

Figure 1 Caltrans E85 Monitoring System Architecture.

The second (ongoing) phase of the project is extending the communications to prove WiFi as well as cellular, and is conducting a 125 vehicle Field Operational Test (FOT) to demonstrate that the system can be expanded to accommodate the entire fleet.

The web based user interface was created within this program to allow for data review and evaluation of refueling activity. Figure 2 shows an example of a specific trip completed during the program with a refueling event. This type of user interface has allowed for determination of vehicle activity relative to refueling. E85 fuel use trends have been evaluated relative to vehicle activity and trip reporting. The analysis has shown that significant trends exist according to vehicle model and operating location.

Figure 2 Caltrans E85 user interface mapping function.

This study has allowed for development, deployment, and evaluation of a telematics architecture for E85 fleet monitoring and fuel use. The initial pilot study identified the potential for having refueling data coupled with vehicle activity. Specific vehicle activity trends impact fuel use and refueling activities. Using an expanded system with similar capabilities can provide needed information for promoting the use of E85 and improving the knowledge of fleet operations and activity.

Our Results To Date

Numerous conclusions have been drawn from the technology implementation, pilot operation, data analysis, and initial results. The extensive analysis of vehicle activity and fuel use has provided key conclusions and areas of interest which include:

- 85 percent is a maximum threshold of ethanol for E85 with actual observed percentages being closer to 75 percent;
- Cellular communications are an effective and reliable means of wireless data transfer, however other wireless technologies with non-recurring costs are being explored for cost savings;
- Once tested and proven on a specific model, the OBD-II connector is the ideal interface to connect fuel monitoring on-board hardware and similar information may be obtained from trucks having a computer data bus.
- Vehicle activity observations, such as trip distance, that effect fuel choice should be further explored to determine significance and frequency of occurrence; and
- GPS aided navigation for refueling can potentially guide drivers to E85 refueling locations when operating in unfamiliar regions.
- This system can easily be adapted for vehicles using other fuel types.
- This system is ideal to adapt for other fleet monitoring activities, such as GPS tracking of equipment location and usage.

This implementation, demonstration, and analysis have provided a foundation and Field Operational Test showing the system is ideal for a full scale deployment of the system through a project in conjunction with the Caltrans Division of Equipment and Caltrans Information Technology. The future system should build upon the strengths of the pilot program while adding attributes. A key attribute is the modular open architecture presented in the Deployment Plan. This architecture creates a framework for future advanced fuel/energy monitoring and affiliated ITS applications. Additionally, improved on-board functionality could assist drivers in knowing current fuel composition, E85 refueling location, and emissions savings. Finally, enhanced web-based applications can assist staff, managers, and fleet operators in characterizing vehicle activity and quantifying fuel use.

The project is scheduled to complete June 30, 2013. Full results and the final report and final deployment plan will be available by mid August 2013.

For Additional Information

For copies of the phase one report and the deployment plan, contact Majed Ibrahim at Majed.Ibrahim@dot.ca.gov, (949) 724-256.

For additional information on the current phase of this project, or related projects, contact Randy Woolley at Randy.Woolley@dot.ca.gov, 949-756-4930.

This research is being conducted by UC Riverside. The principle Investigator is Professor Matt Barth, barth@cert.ucr.edu.

The principle investigator is Michael Todd, mike@cert.ucr.edu.

APPENDIX B: DEPLOYMENT PLAN

Fleet Telematics System for Fuel Monitoring and ITS Applications

EXECUTIVE SUMMARY

A vehicle activity based fuel monitoring telematics system has been demonstrated in a 100 vehicle deployment program for the Caltrans E85 fleet. A system consisting of 100 E85 vehicles connected with a centralized database server has been implemented for four districts. The fuel monitoring is being completed for General Motors E85 alternative fueled sedans and trucks. The telematics system monitors real time fuel use, vehicle position, and vehicle operation and reports trip by trip vehicle activity to a centralized server. The centralized server maintains historical fuel use and vehicle activity data to be accessed by staff and program managers via a web browser based user interface. The system is designed to be expandable across all districts integrating hundreds of vehicles of varied models and fuel types. The system is also designed to provide a base architecture for expanded ITS applications. The telematics system is expected to provide all districts with accurate fuel use and vehicle activity information while allowing for the future deployment of additional ITS applications.

1. TECHNOLOGY TO BE DEPLOYED

Caltrans has invested a significant amount of funding into alternative fueled vehicles, as well as the fuel they use. Currently there are hundreds of alternative fueled vehicles in the Caltrans fleet, ranging from ethanol (E85) vehicles to bi-fueled pickups. In order to better understand their alternative fuel consumption, a telematics-based system has been developed that can monitor fuel use, fuel mix, refueling locations and times. The architecture of the system is shown in Figure 1. This system can be expanded to include additional ITS applications.

The overall goals of the technology deployment are to:

1. Integrate and deploy a system that can meet the needs of Caltrans to better manage their alternative fueled vehicle fleet;

2. Provide supervisors and managers with a web-based means to manage their vehicle fleet that can potentially lead to drivers modifying their behavior to increase their use of alternative fuels; and,

3. Provide a telematics and server architecture that will allow for future integration of ITS telematics based technologies.

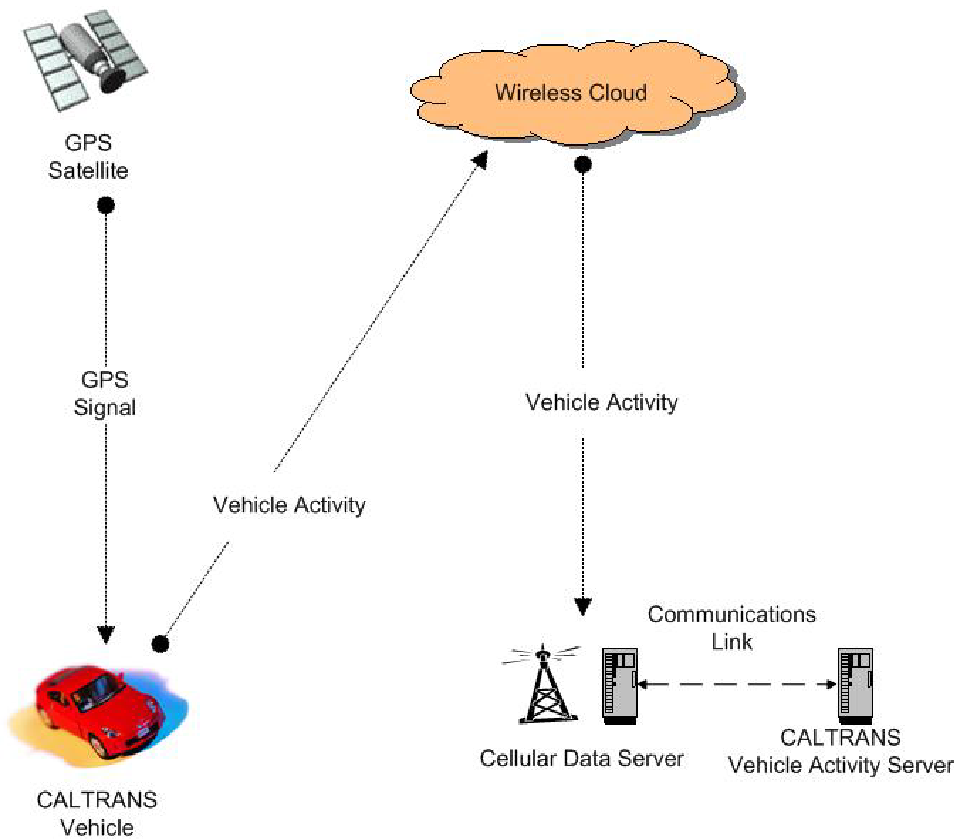

Figure 1. Caltrans E85 fuel monitoring system architecture.

1.1 Background/History

UC Riverside's Center for Environmental Research and Technology (CE-CERT) has been developing telematics system designs for general vehicle activity research programs for a number of years. From 1999 – 2007, CE-CERT developed and operated the world's largest campus-based carsharing operation that relied heavily on a cellular and RF based telematics architecture (see [Barth & Todd, 1999; Barth et al, 2000a, 2000b, 2001a, 2001b, 2002a, 2002b]). Specific on-board hardware was developed and installed on nearly 50 vehicles, across four different vehicle types. This on-board hardware provided not only a means of monitoring a variety of vehicle functions (including location via GPS), it also was a critical part of vehicle access control. The on-board hardware that was developed at UCR has several useful attributes: 1) approximate two-meter positioning accuracy using an embedded differential GPS (DGPS) receiver; 2) two-way, wide-area communications using an embedded general packet radio service (GPRS) modem; and 3) an embedded microcontroller that is programmable to perform a variety of tasks.

This on-board hardware and data acquisition system has also been used to monitor vehicles in other research programs. For example, it is currently being used in monitoring Nissan Motor Company's fuel cell vehicle fleet that is currently deployed in California and Arizona, returning critical vehicle operational data to Nissan engineers as the vehicles are driven in the real-world (see [Nissan, 2004]). The system has also been deployed in a number of instrumented vehicles with the purpose of providing lane-level positioning accuracy (i.e., it reliably reports which lanes the instrumented vehicle is traveling in at any second) [Du, 2005; Barth & Du, 2005]. This hardware architecture is now being slightly modified to carry out research in eco-friendly navigation, providing information to drivers about the most environmentally friendly route from a CO_2 and pollution point of view [Barth et al., 2007]. This previous experience and development of on-board telematics has provided UCR with the knowledge and experience to implement and expand Caltrans' fuel monitoring capabilities.

1.2 Problem and Opportunity

Microcontroller based vehicle monitoring systems are a common ITS implementation for fleet applications. The unique specification for the implemented system is the integration of alternative fuel monitoring through the OBD diagnostics data bus. A novel approach to the overall system architecture is also being integrated. The communication system architecture being developed allows integration of modular on-board vehicle hardware. Additionally, a database server structure is being proposed that allows modular database processing software. This architecture allows for integration of hardware provided by independent vendors and software provided by independent agencies. This technology deployment will create a base architecture, hardware, software, and structure that allows for alternative fuel monitoring with the open architecture expansion to many ITS technology providers. The modular architecture also allows for any combination of TCP/IP wireless protocol, such as, 802.11bgn (Wi-Fi), 802.11p (DSRC), or cellular data transmission (GSM/GPRS).

1.3 Technology Description

In order to remotely monitor a vehicle's E85 fuel usage, fuel mixture, and fueling locations and times, the architecture shown in Figure 2 has been implemented. This architecture is similar to other successful systems already in use. The architecture requires on-board vehicle telematics capable of tracking the vehicle using position information from the DGPS receiver. The microcontroller will also have the ability to communicate with the overall system via TCP/IP, sending information on the vehicle and its position. In addition, the microcontroller interfaces with the vehicle through the OBD-II data port. Details of this interfacing are described in detail in the following section.

To fully achieve these goals with a technology implementation that is non-proprietary and non-vendor specific a modular architecture is being proposed. This modular approach consists of three modules with specific communication protocols to be defined by this proposed work.

Vehicle Hardware Module

- Mobile wireless communication based on TCP/IP addressing: Cellular data, DSRC and/or Wi-Fi
- Defined universal interface (OBD-II), communication standard (TCP/IP), and messaging protocol (vehicle-to-database) allows future hardware migration

Database Repository Module

- Communication standard (TCP/IP) and messaging protocol to send/receive information from vehicles

- Defined universal data fields and data structures for present and future vehicle activity – allows for expansion to different fuels, activities, applications

Web Server/Client Interface Module

- Internet browser based application
- Communication standard and messaging protocols for data transfer with database repository
- Ability for vehicle mapping reports, fuel reports, fuel consumption trends

To fully achieve these goals with a technology implementation that is non-proprietary and non-vendor specific, a modular architecture is being proposed. This modular approach consists of three modules with specific communication protocols to be defined by this proposed work. The modular approach allows the system components to be agnostic to any other module. The diagram below (Figure 2) provides highlights the three major components of the system.

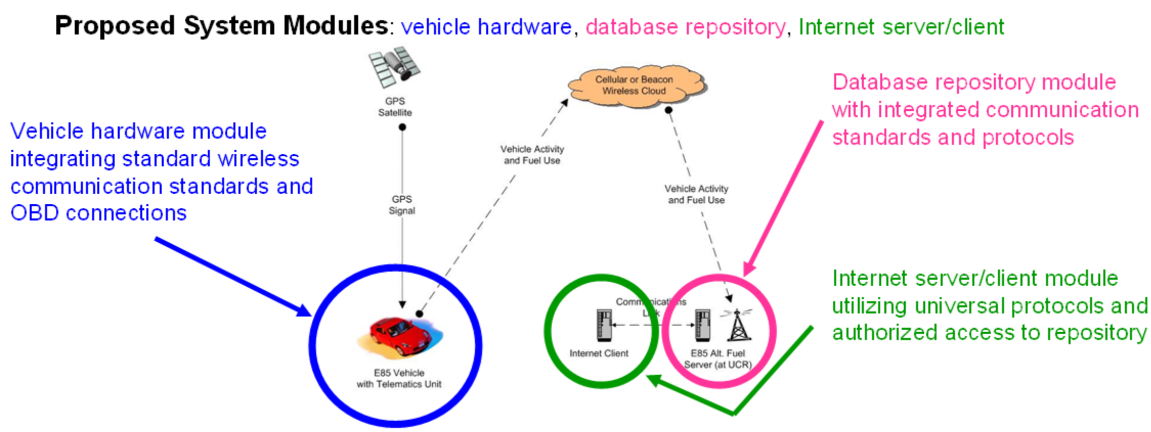

Figure 2. Proposed architecture for future deployment.

The primary goal of the modular design is to allow the system to be expandable and agnostic to a specific creator/vendor. For example, a hardware vendor could produce the vehicle side hardware. A second vendor could be used to produce the Web Server/Client interface and finally a third vendor could be contracted to support the Database Repository Module. This approach of open design provides the end user with a very cost effective and maintainable solution. The modular design also ensures that the future support and growth of the system will not be dependent on a sole vendor to provide the solution.

Figure 3 below depicts the flow of data from the vehicle to the end user. The diagram provides a map of the data flow and all the services/programs that are required to display/generate the web based interface/reports. There are three major modules of the design a shown below:

- Vehicle Hardware Module (VHM) – Consisting of on-board telematics hardware/firmware;
- Data Repository Module (DRM) – Comprising the hardware and software required to process and manage the database; and,

- Web Client Interface (WCI) – Interface and data mangagement components to share and present database information.

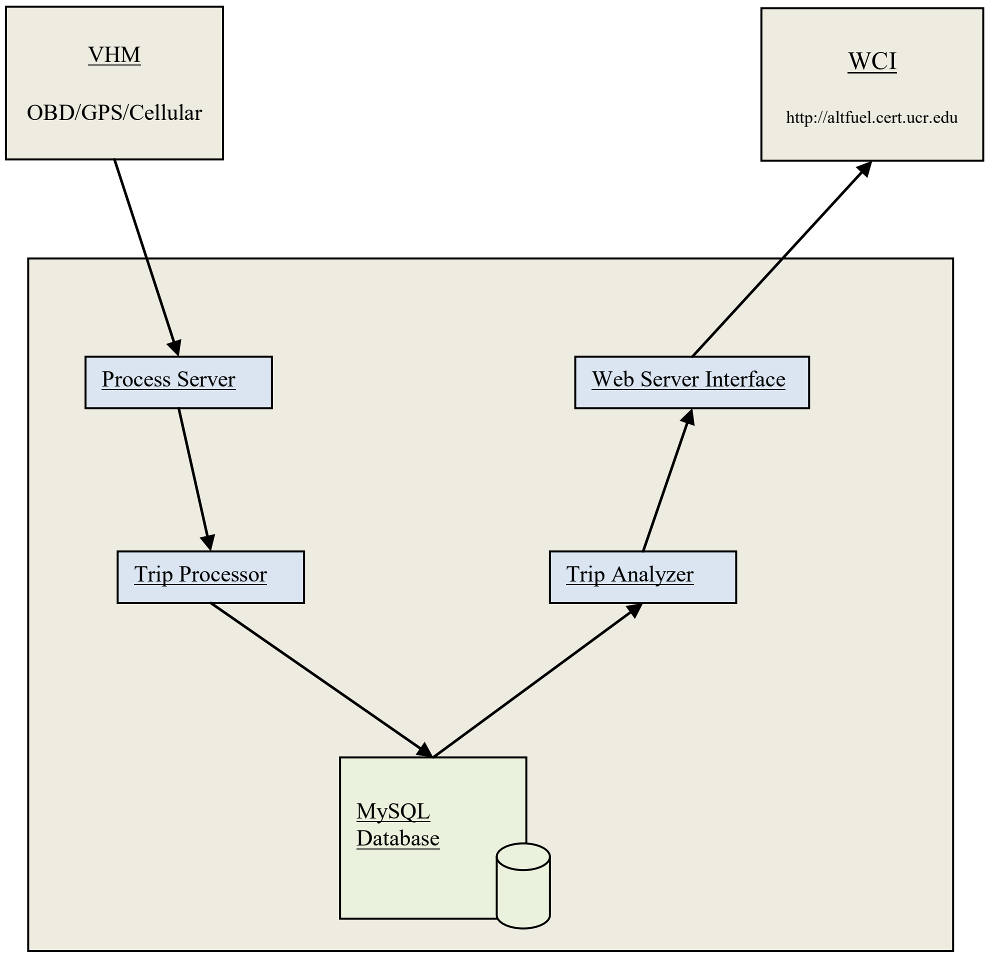

Figure 3. Server data flow diagram for telematics and web client programs.

The flow of data between the modules requires specific communication protocols and formats. The goal of this deployment is to create a open standard that can be utilized and adopted by the telematics industry for the mantenance of vehicle activity databases.

1.4 Technology Developer

CE-CERT was established in 1992 as a multi-disciplinary research center. It serves as a model for partnerships among industry, government, and the academic community, focusing on transportation and air quality research. CE-CERT has assembled a diverse team of researchers from numerous engineering disciplines, the physical sciences, and related fields. CE-CERT maintains a full-time, permanent staff of researchers (ranging from degreed principal investigators to technicians) to conduct research projects and operate our laboratories. These engineers and scientists collaborate with colleagues from all departments in the College of

Engineering, other schools and colleges on campus, and other institutions around the world. They also supervise research by graduate and undergraduate students enrolled in the College of Engineering and other departments on campus. This breadth of expertise enables CE-CERT to take a "systems approach" to solving transportation and environmental problems and opens new and creative avenues for addressing some of the most difficult challenges facing society today.

1.5 Stakeholders/Users

The system development is initially intended to facilitate the deployment of alternative fueled vehicles within the Caltrans fleet. Successful implementation is expected to provide an architecture that can be utilized for numerous statewide ITS applications.

Caltrans manages more than 50,000 miles of California's highway and freeway lanes, provides inter-city rail services, permits more than 400 public-use airports and special-use hospital heliports, and works with local agencies. Caltrans carries out its mission of improving mobility across California with six primary programs: Aeronautics, Highway Transportation, Mass Transportation, Transportation Planning, Administration and the Equipment Service Center. The department has been active in moving the people and commerce of California for more than 100 years from a loosely connected web of footpaths and rutted wagon routes to the sophisticated system that today serves the transportation needs of more than 30 million residents.

The deployment program has currently been deployed for Districts 4, 7, 8, and 11. Each district has integrated a motorpool vehicle fleet with Wi-Fi communications. The statewide deployment will allow for analysis of geographical variation associated with a large fleet deployment.

1.6 Benefits of Technology

The developed system provides a platform and architecture to monitor alternative fuel usage in the Caltrans fleet, and provides a method for managers and supervisors to access these data in a meaningful way. The system includes on-board monitoring hardware that has telematics capabilities of sending this information to a system server that can be readily accessed via the Internet and/or Caltrans' intranet. The open architecture of the system provides a base platform for expanded ITS implementations. The open architecture also promotes the integration of technologies from many different ITS service providers and technology integrators. Successful deployment will allow for improved operations of alternative fueled vehicles. The increased efficiency of fleet operations and will allow for cost savings while achieving lower vehicle emissions.

2. MARKETING

2.1 Market Research

The development and implementation of on-board vehicle telematics has provided a technology platform for numerous applications. These applications serve industries in logistics, safety, insurance, and consumer electronics (personal navigation devices). The well developed telematic industries are detailed below:

- Vehicle/Trailer tracking - is a way of monitoring the location, movements, status and behavior of a vehicle/trailer or fleet of vehicles. This is achieved through a combination of a GPS(GNSS) receiver and an electronic device (usually comprising a GSM/GPRS/SMS modem or satellite data transceiver installed in each vehicle/trailer) communicating with the user (dispatching, emergency or coordinating unit) and/or web-based software. The data processed into information by management reporting tools in conjunction with a visual display on computerized mapping software.

- Fleet management - is a function which allows transportation companies to remove or minimize the risks associated with vehicle investment, improving efficiency, productivity and reducing their overall transportation costs, providing 100% compliance with potential government legislation. These functions can either be dealt with by an in-house fleet management department or an outsourced fleet management provider.

- Vehicle navigation - in the context of vehicle telematics is the technology of using a GPS and electronic mapping tool to enable the driver of a vehicle to locate a position, then route plan and navigate a journey. Real time wireless communications allow for the added benefit of traffic updates and updated regional information.

- Vehicle safety – applications utilize telematics to improve car safety and road safety. The applications include electronic sub-systems in a car or other vehicle(s) for the purpose of exchanging safety information, about such things as road hazards and the locations and speeds of vehicles, over short range radio links. Emergency warning system for vehicles telematics have been developed and implemented with standardization of vehicle-to-vehicle — infrastructure-to-vehicle — and vehicle-to-infrastructure real-time Dedicated Short Range Communication (DSRC) systems. Much of the efforts are being lead by the national VII coalition.

- Shared use vehicle systems - telematics technology has allowed carsharing organizations to emerge, such as City Car Club, Zipcar, and CityCarShare. Telematics-enabled computers allow agencies to track members' usage and bill them on a pay-as-you-drive.

- Insurance, Tolling, Road Tax - The basic idea of telematic based payments is that a driver's vehicle activity is monitored directly while the person drives and this information is transmitted to a billing agency. The agency then assesses the cost associated with the vehicle activity. The telematics typically consist of a GPS, wireless communication, and on-board processing.

The listed telematic industries are defined markets of vehicle location applications. These industries all possess wireless data transmission via proprietary protocols and architectures. This deployment plan targets the development of an open architecture communication protocol that would allow for a managed database serving most telematic industries. Meaning, a single database could be shared among several industries. The initial target industry is fleet management of alternative fueled vehicles.

2.2 Market Strategies

The initial deployment will bring together existing providers of telematic and fleet management devices. These entities will be provided with the opportunity to partner in the initial system development and deployment. Simultaneously, efforts will be put forth to develop SAE/ISO standards for the communication protocols. These protocols will provide for the adoption of the described open system architecture. This deployment plan does not directly lead to the marketing of specific hardware or software. The deployment will lead to the development and implementation of an open architecture database and protocol that enhance future operations and provides cost savings in fleet management.

3. COMMERCIALIZATION

3.1 Intellectual Property

The developed system architecture, hardware, and software do not currently possess intellectual property licenses, copyrights, or patents. The commercialization of this technology and architecture is proposed to provide an open architecture with developer guides for the future third party integrators.

3.2 Evaluation of the Technology and its Commercialization Potential

UCR will complete an emissions evaluation of the program fleet E85 fuel use. The E85 comparison will provide an analysis of tailpipe gaseous emissions (CO, HC, NOx) and greenhouse gas emissions (GHG). This emissions analysis will then be extrapolated to economic incentives for E85 fleet deployment with fuel monitoring. Additional economic incentives will be explored for E85 fuel use monitoring, such as, navigational aids for E85 refueling location determination. This effort will create supportive analysis that Caltrans can integrate with internal economic and operational data. This effort is planned during the next phase of system development.

3.3 Evaluate Potential Vendors to Commercialize Technology

UCR will perform outreach to vendors to gain program participation. The goal is to achieve participation from several vendors that will each equip from 10 to 30 vehicles with their hardware for demonstration purposes. This task will target 100 vendor equipped vehicles. The vendors will be expected to incur the installation and hardware cost through the demonstration period. The vendors will receive program information and guidance relating to database communication and server connections to the repository. Caltrans will supply the cellular data accounts for the vendor installed equipment.

3.4 Cost of Technology

UCR will provide hardware for 25 vehicles on up to 5 different models (including the previously equipped models). This hardware will demonstrate the functionality expected from the vendor supplied telematics. Deployment of UCR installed telematics will consist of up to four locations.

The next phase of work proposed for UC Riverside is projected to cost $360,000. Upon completion of that phase, approximately 125 vehicles will be equipped and operating within the proposed system architecture. Successful implementation of the system will allow for future vehicle expansion at a per vehicle cost. Each additional vehicle will likely cost $300-$500 per vehicle and a one time installation. The database management would be a separate annual cost negotiated with a third party or supported internally with Caltrans. Finally, the user interface would be a final cost to be supported by a third party or internally within Caltrans. The database management and user interface costs will be estimated more accurately during the next phase of development.

4. DEPLOYMENT STRATEGY

The first phase of work on this project developed, implemented, and evaluated a system that can monitor alternative fuel usage in the Caltrans fleet, and provide a means for managers and supervisors to access these data in a meaningful way. The developed system includes on-board monitoring hardware that has telematics capabilities of sending this information to a system server that can be readily accessed via the Internet. A prototype system had been developed in Phases I and II and evaluated feasibility as part of the deployed pilot study. The Phase III deployment creates an open architecture that allows third party vendors to supply hardware and system support. The proposed database and communication protocols will remove the need for proprietary hardware and software.

The next phase of deployment consists of four goals:

1) Integrate and deploy a *full-scale* system that can meet the needs of Caltrans to better manage their alternative fueled vehicle fleet;
2) Provide supervisors and managers with a web-based means to manage their vehicle fleets that can potentially lead to drivers modifying their behavior to increase their use of alternative fuels;
3) Provide a telematics and server architecture that will allow for future integration of additional ITS technologies; and,
4) Evaluate vehicle activity and system implementation impacts.

These goals have been outlined as specific tasks over a three year contract proposal. The tasks have been provided with budgets and timelines.

5. DEPLOYMENT PLANNING ACTIVITIES

5.1 Timeline of Milestones and Deliverables

The proposed tasks are to be conducted during the next phase of the proposed contract. The period of performance is 36 months from Notice to Proceed which is currently July 1, 2010. The start and end months for each task are listed in Table 1 below. A corresponding Gantt chart of the project is provided in Figure 4.

Five major deliverables are proposed, listed in Table 2. The first is a Final Report, which will contain a comprehensive project description, including the communication and database protocols developed in Tasks 5 and 6. The second is an updated Deployment Plan which has been described in Task 9. An Emissions and Economic evaluation will be provided as a third deliverable. At the end of the project, the system hardware will be provided to Caltrans as another deliverable. Further, protocol definitions and integration methods will be provided to

Caltrans and participating vendors as part of Tasks 5 and 6. Note that the deliverables also include quarterly progress reports in accordance with the Caltrans' procedure. These progress reports will be submitted within 15 days of the end of quarters.

List of Tasks	Start Month	End Month
1 Convene TAG, Conduct Kickoff Meeting	1	1
2 Quarterly and Final Reports	4	36
3 Vehicle Telematics Enhancement	1	6
4 Data Repository Hardware Improvements	2	4
5. Vehicle Firmware Development	4	8
6. Data Repository Software Development	1	4
7. Web Interface Development	6	12
8. Deployment Plan Review	4	36
9. Emissions Evaluation and Economic Incentives in support of a Business Plan	16	20
10. Vendor Recruitment	2	24
11. UCR Telematics Implementation	12	36
12. System Operation	18	36

Table 1. Start and end dates of the proposed tasks.

List of Deliverables	Contract Month of Completion
1. Final Report	36
2. Updated Deployment Plan	36
3. Emissions and Economic Evaluation	20
4. Project Hardware (telematics and server)	36

5. Protocol Definition Documentation	18

Table 2. List of proposed deliverables and their date of completion

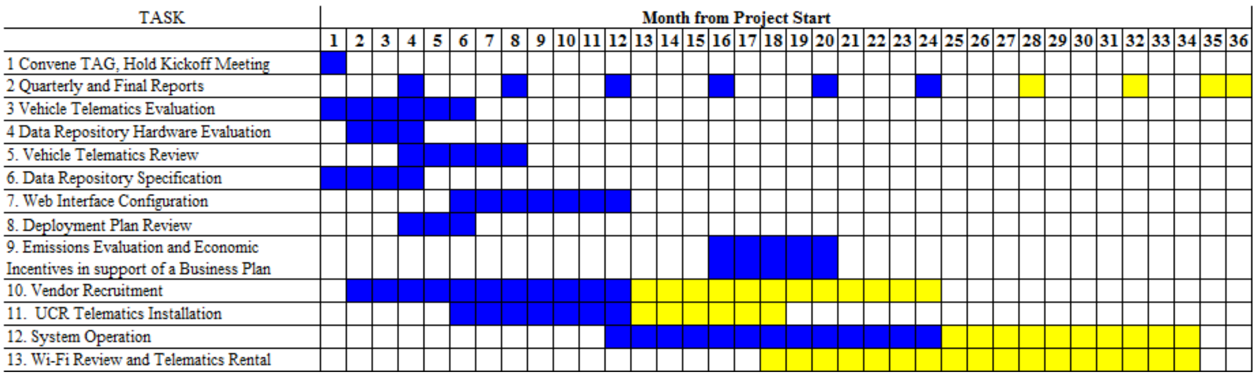

Figure 4. Gantt chart of the proposed project.

5.2 Work Breakdown Structure

The next phase of research consists of project management tasks, research tasks, and deployment tasks:

- **Project Management** consisting of TAG / kickoff meetings, quarterly reporting, and a final report;

- **Research Tasks** includes the system enhancement, protocol development and the evaluation of the system into an expanded fleet of vehicles;

- **Deployment** of the components into an expanded fleet of vehicles while encouraging the participation of third party fleet management technology providers.

CE-CERT will provide the needed personnel, equipment, and facilities, and exert their best efforts within time and budget constraints, to complete the following tasks that will attain the deployment objectives. The transition from the current implementation to the proposed system architecture will require the enhancement of hardware and software with the development of new protocols. The new protocols will allow for the transition to a non-proprietary architecture. Third party vendors will be recruited to provide vehicle hardware that will transmit data to the data repository module.

5.3 Resource Loaded Schedule and Budget

It is anticipated that this next phase of development can be completed by CE-CERT for $363,567. The detailed budget has been detailed in the previously submitted proposal. The budget is broken down by personnel, equipment and cost by task. An estimated $5,000 is included for a literature review service.

This next phase of development will be carried out by the Principal Investigator (PI) Matthew Barth, along with Michael Todd, a Principal Development Engineer who has extensive experience with telematics-based vehicle activity data systems. Assisting with the research will be a part-time graduate student researcher who has the expertise in microcontroller development. A Junior Development Engineer will also spend 20% time developing the system server, and to provide support throughout the rest of the project. Finally, undergraduate student assistants will be used to help with development, vehicle installations, and operation. It is expected that this next phase of development can be successfully completed in 36 months. Details on deployment costs are further detailed as follows.

- **Development Cost:** Tasks 3, 4, 5, and 6 address system improvements and development of protocols. To enhance the initial vehicle and system hardware and software, including protocol development, the cost the associated tasks without vehicle hardware is approximately $149,208. This essentially includes the time and effort of the engineering staff for system development in tasks 3 through 6.
- **Per Vehicle Hardware Cost:** Once the initial enhanced hardware is completed and thoroughly tested, the remaining per vehicle cost will be approximately $950 in telematics hardware and $200 in vehicle interfacing hardware, for a total of $1,150 per vehicle. If university overhead is counted in the cost, the per vehicle cost is $2,300.
- **Deployment and Operation Costs:** Deployment and operation consists of Tasks 11, 12 and 13. Once the initial prototype vehicles have been instrumented and tested, the remaining vehicles can be modified and added to the system. The cost to deploy and operate this hardware in the 25 vehicle fleet is approximately $199,748 including labor and travel.

5.4 Training

To fully achieve the deployment goals with a technology implementation that is non-proprietary and non-vendor specific a modular architecture is being proposed. This modular approach consists of three modules with specific communication protocols to be defined by this development effort. The modular approach allows the system components to be agnostic to any other module. This architecture requires documented protocols and communication methods. Additionally, training and technical interaction is required for vendor recruitment. UCR will provide all training and technical interaction required for third party participation.

5.5 Maintenance and Operations

UCR will oversee the system operation, data collection, and server/client interface. The vendor equipped vehicles will report data to the UCR developed and UCR monitored repository. Once the data is received from the third party vendor equipped vehicles, UCR will manage the data and representation of information to the client interface.

6. CONCLUSIONS

Over time, the Caltrans has invested in a variety of alternative fueled vehicles as part of its in-use vehicle fleet. By using alternative fueled vehicles that run on ethanol, compressed natural gas (CNG), propane, or bio-diesel, there should be a quantitative improvement in CO_2 emissions, better fuel economy, and general support for energy independence. However, it has been very difficult to determine how much these vehicles are actually using alternative fuels, especially when the vehicles have bi-fuel capability.

This deployment plan has detailed the development, implementation, and evaluation of a system that can monitor alternative fuel usage in the Caltrans fleet, and provide a means for managers and supervisors to access these data in a meaningful way. The developed system includes on-board monitoring hardware that has telematics capabilities of sending this information to a system server that can be readily accessed via the Internet. The open architecture and non-proprietary system will allow for future integration with an expanded fleet and intelligent transportation system applications. Third party vendor participation and recruitment is a primary goal of the deployment strategy. Successful deployment will allow for improved operations of alternative fueled vehicles. The increased efficiency of fleet operations and will allow for cost savings while achieving lower vehicle emissions.

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