RITA Intelligent Transportation Systems Joint Program Office

AERIS – Applications for the Environment: Real-time Information Synthesis State-of-the-Practice Support

State-of-the-Practice Assessment of Technology to Enable Environmental Data Acquisition

Submitted to
U.S. Department of Transportation
Federal Highway Administration

Contract No. DTFH61-06-D-00006

FHWA-JPO-11-134

Submitted By
Booz Allen Hamilton

June 21, 2011

U.S. Department of Transportation
Federal Highway Administration
Research and Innovative Technology Administration

Produced by AERIS – Applications for Environment: Real-time Synthesis State of the Practice Support
ITS Joint Program Office
Research and Innovative Technology Administration
U.S. Department of Transportation

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-11-134		

4. Title and Subtitle	5. Report Date
AERIS – Applications for the Environment: Real-time Information Synthesis State-of-the-Practice Support: State-of-the-Practice Assessment of Technology to Enable Environmental Data Acquisition	June 21, 2011
	6. Performing Organization Code
7. Author(s) Emily Parkany, Matthew Dorfman	8. Performing Organization Report No.
9. Performing Organization Name And Address Booz Allen Hamilton 8283 Greensboro Drive McLean, Virginia 22102	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-06-D-00006
12. Sponsoring Agency Name and Address Research and Innovative Technology Administration (RITA) U.S. Department of Transportation 1200 New Jersey Avenue, SE Washington, DC 20590	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes	

16. Abstract

In this report, vehicle-based and infrastructure-based data acquisition technologies are assessed. Vehicle-based technologies include methods for accessing the Controller Area Network (CAN) Bus on heavy vehicles, the On-Board Diagnostic (OBD II) on smaller vehicles such as automobiles and non-commercial vehicles, fleet-based systems, the Portable Emissions Measurement System (PEMS), and connected vehicle technologies. Infrastructure-based technologies include remote sensing devices (RSDs), air quality monitoring stations, and environmental sensor stations. At the end of the report, the advantages of a hybrid of vehicular and infrastructure-based data acquisition technologies are briefly described. For each technology:

- The technology is described;
- Applicable vehicles (if appropriate) are provided;
- Example deployment locations are provided;
- Available costs are discussed; and
- Appropriate ITS Standards related to the technology are provided.

17. Key Words	18. Distribution Statement
AERIS, Environmental Data, Data Acquisition Technologies, Environmental Data Sensors, RSD, PEMS, OBD II, Intelligent Transportation Systems, ITS	No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified.	Unclassified.	48	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

EXECUTIVE SUMMARY

Presented here is a *State of Practice Assessment of Technology to Enable Environmental Data Acquisition* report for the Applications for Environment: Real-time Information Synthesis (AERIS) State-of-Practice support project. This report is one of three reports prepared for this foundational research project which is part of Phase I of U.S. DOT's AERIS program. The other reports are a State-of-Practice of Travel Demand and Activity-Based Models and a State-of-Practice of Emissions Models.

Objectives

There are three general objectives to this report:

- Describe the environmental data needed to support the AERIS program
- Provide descriptions of data acquisition technologies including vehicle-based technologies and infrastructure-based technologies
- Provide recommendations for how to collect environmental data for the AERIS program including a description of new methods and technologies as appropriate.

Data Needed to Support the AERIS Program

There are four reasons why environmental data will be collected for the AERIS program. These include:

- Enhance existing databases with environmental data that represents current conditions
- Data to validate emissions models and to calibrate traffic simulation models
- Refine/optimize AERIS Transformative Concepts. Additionally, the availability of environmental data will be an input to the AERIS Transformative Concepts and will help define the concepts
- Model impacts of AERIS Transformative Concepts.

Assessing data resources and opportunities is an ongoing effort through the 5-year life of the AERIS program. Developing Transformative Concepts and Modeling the Transformative Concepts are Track 2 and Track 3 efforts of the 5-year AERIS program.

Several types of data can be collected including emissions/air quality-related data, meteorological data, weather data, and vehicle-related data.

Assessment of Data Acquisition Technologies

In this report, vehicle-based and infrastructure-based data acquisition technologies are assessed. Vehicle-based technologies include methods for accessing the Controller Area Network (CAN) Bus on heavy vehicles, the On-Board Diagnostic (OBD II) on smaller vehicles such as automobiles and non-commercial vehicles, fleet-based systems, the Portable Emissions Measurement System (PEMS), and connected vehicle technologies. Infrastructure-based technologies include remote sensing devices (RSDs), air quality monitoring stations, and environmental sensor stations. At the end of the report, the advantages of a hybrid of vehicular and infrastructure-based data acquisition technologies are briefly described. For each technology:

- The technology is described;
- Applicable vehicles (if appropriate) are provided;
- Example deployment locations are provided;
- Available costs are discussed; and
- Appropriate ITS Standards related to the technology are provided.

The report provides more description of the technologies. Each technology is named and described briefly below:

- **On-Board Diagnostic II (OBD II) and Engine On-Board Recorder (EOBR).** On-Board Diagnostic systems are intended to trigger the engine's "check engine" light if it detects that emissions are greater than 1.5 times what is expected for that vehicle model and year. With an EOBR reader, additional information (not just "on" or "off" for the check engine light) can be obtained.

- **Controller Area Network (CAN) Bus** provides additional engine and emission-related information compared to most OBD II systems. CAN bus data on commercial vehicles must follow specific standards. It may be available on light vehicles but non-commercial data is often proprietary and varies by manufacturer.

- **Here-I-Am, Aftermarket Safety Devices, Retrofit Devices, and Integrated Devices**. These are all **Connected Vehicle technologies**. Connected Vehicle technologies are used for Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications and are often thought of as safety-related. However, they can acquire CAN bus and additional data for mobility and environmental applications including the AERIS Transformative Concepts.

- **Portable Emissions Measurement System (PEMS).** A PEMS system can measure the precise tailpipe emissions of a specific vehicle. One PEMS system may cost $100,000 or more.

- **Fleet-Based Systems** are used by commercial vehicle fleets to help track trucks in their fleet. Often utilizing cellular networks or "data dumps" when trucks return to garages, they may not provide the real-time data desired by the AERIS program.

- **Remote Sensing Devices.** This is an infrastructure-based data acquisition technology that measures tailpipe emissions of passing vehicles. This provides data for all vehicles passing one point.

- **Air Quality Monitoring Stations.** These are monitored and maintained by the EPA and provide area-wide environmental measures from static and mobile sources. Vehicle-based emissions may be difficult to distinguish from static emission sources such as landfills or factories.

- **Environmental Sensor Stations**. An environmental sensor stations (ESS) is a collection of devices or sensors including wind, temperature, and barometers. Road Weather Information Systems are information systems enabled by the devices on ESS. Most U.S. ESS installations do not include air quality sensors.
- **Hybrid Approaches.** With hybrid approaches, static sensors that obtain data at one point may be combined with vehicle-based data acquisition systems that collect data from instrumented vehicles. Both data sources are limited (not all vehicles but covering a wide spatial area or all vehicles at a point, for example), but the combined data may be better than one type of data.

The technologies are described using several criteria in **ES-Table 1**. These criteria include cost of data collection, difficulty of installation, potential spatial coverage, coverage of vehicle types, 2016 penetration of vehicles, mobile vs. static, direct emission measurement, and granularity. Most of the cells in the table include 1 to 5 ratings for these criteria according to the legend provided below the table.

ES Table 1: Mapping of Data Acquisition Technologies and Preferred Criteria

Technology	Criteria							
	Cost of Data Collection	Difficulty of Installation	Potential Spatial Coverage	Coverage of Vehicle Types	2016 Penetration of Vehicle Pop.	Mobile Data vs. Static Data	Direct Emission Measurement	Granularity
OBD II + Engine On-Board Recorder (EOBR)	5	3	4	4	1	M	3	4
CAN Bus + EOBR	5	3	4	2	1	M	3	4
Here-I-Am + Connected Vehicle infrastructure	5	4	4	5	1	M	1	4
Aftermarket Safety Device+ Connected Vehicle infrastructure	4	3	4	4	3	M	1	4
Retrofit Device or Integrated Device+ Connected Vehicle infrastructure	3	5	4	2	2	M	1	4
Portable Emissions Measurement System (PEMS)	1	3	4	4	1	M	5	5
Fleet-Based Systems	3	2	4	1	2	M	3	3
Remote Sensing Devices (RSDs)	2	4	1	5	5	S	4	4
Air Quality Monitoring Stations	4	3	2	N/A	N/A	S	3	1
Environmental Sensor Stations	4	3	2	N/A	N/A	S	4	1
Hybrid Approach—PEMS and RSDs	1	3	4	2	3	B	4	5
Hybrid Approach—Connected Vehicles and RSDs	2	3	5	4	4	B	4	5

Notes: Most cells include a 1 to 5 rating of how well the technology fits the criteria. The following legend explains the meanings of the range of numbers or the letters provided in each column. N/A in a cell means the criteria is Not Applicable for that technology.
Cost: 1 is High (for example, $100,000 per vehicle); 2 represents a high cost of sensor, but it is used to collect data from multiple vehicles, 3 is $500-$1000 per vehicle, 4 is $100-$500 per vehicle; 5 is Low (less than $100 per vehicle).
Difficulty of Installation: 1 is Difficult (requires professionals to install and calibration); 3 (professional installation; minor calibration); 5 is Easy (factory-installed; no calibration).
Potential Spatial Coverage: 1 is Less (coverage of individual vehicles at only one point); 2 may be an aggregate of vehicles but mostly at a point; 4 is Coverage on all types of roads and over a large spatial area but not including all vehicles; and 5 is Coverage on all types of roads over a large spatial area aggregated for multiple vehicles.
Coverage of Vehicle Types: 1 is fewer types (only commercial vehicles or fleet vehicles or automobiles); 5 includes all vehicle types.
2016 Penetration of Vehicle Pop: 1 = specially equipped test vehicles only; 2 = present in few U.S. vehicles; 3= present in some U.S. vehicles; 4= present in many U.S. vehicles; 5= present in all U.S. vehicles.
Mobile Data vs. Static Data: M= Mobile, S= Static, B=Both.
Direct Emission Measurement: 1 individual emission data is not obtained; 4 emission data is obtained by not from individual vehicles; 5 direct tailpipe emissions are obtained from individual vehicles.
Granularity: 1 is Coarse (not possible to identify individual vehicles); 5 is Granular (data is obtained from individual vehicles).

Mapping of Data Acquisition Technologies with Desired Environmental Data

ES Table 2 provides a mapping of the data acquisition technologies with desired environmental data.

ES Table 2: Environmental Data Elements Mapped to Specific Data Acquisition Technologies

Data Element	Technology											
	Vehicle Data Sources		Connected Vehicle Technologies			PEMS	Fleets	Infrastructure-based Technologies			Hybrid Approaches	
	CAN Bus	OBD II	Retrofit and Integrated Devices	After-Market Safety Device	Here I Am	PEMS	Fleet-Based Systems	Remote Sensing Devices (RSDs)	Air Quality Monitoring Stations	Environmental Sensor Stations	Hybrid Approach – PEMS and RSDs	Hybrid Approach – Connected Vehicles and RSDs
Particulate	X	X	X				X	I	I	P	I	I

Data Element	Technology: Vehicle Data Sources		Technology: Connected Vehicle Technologies			Technology: PEMS	Technology: Fleets	Technology: Infrastructure-based Technologies			Technology: Hybrid Approaches	
	CAN Bus	OBD II	Retrofit and Integrated Devices	After-Market Safety Device	Here I Am	PEMS	Fleet-Based Systems	Remote Sensing Devices (RSDs)	Air Quality Monitoring Stations	Environmental Sensor Stations	Hybrid Approach – PEMS and RSDs	Hybrid Approach – Connected Vehicles and RSDs
Emissions/Evaporative Emissions												
Criteria Pollutants	X	X	X				X	I	I	P	I	I
Carbon Monoxide	X	X	X				X	I	I	P	I	I
Nitrous Oxide (NOx)	X	X	X				X	I	I	P	I	I
Greenhouse Gases/Hydrocarbons	X	X	X				X	I	I	P	I	I
Temperature	I	I	I				I			I		
Barometric Pressure	I	I	I	I			I		P	I		
Relative Humidity									P	I		
Precipitation										I		
Pavement Temperature										I		
Wind										I		
Average Vehicle Speed	I	I	I	I	M		P	P			P	P
Instantaneous Vehicle Speed	I	M	I	M	M							
Acceleration/ Deceleration Rates	I	M	I	M	M							
Braking	I	M	I	M	M							
Engine Idling	I	M	I	M								
Engine Starts	I	I	I	M			I					
Tail-Pipe Emissions	M	M	M	M		I	M	I			I	I
Engine speed RPM (Rotations per minute)	I	I	I	I								
Fuel consumption	I	I	I	I			I					
Air / Fuel Ratio	I	I	I	I								
Intake Temperature	I	I	I	I								
Battery Voltage	I	I	I	I								
Vehicle Mileage	I	I	I	I								
Vehicle Fuel Type	P	P	P	P								
Time Spent Idling	M	M	M	M	M							
Idling Location			M	M	M							

Key: X=Indicator light is switched on if emissions eXceeds 1.5, the standard level for the vehicle model year; I = Included; P = Possibly Included; M = may be able to be modeled based on data provided by this source.

Recommendations

At the end of the report, several recommendations for the collection of environmental data for AERIS are provided. In short, these recommendations include:

- Public agencies and researchers desiring more environmental data should deploy more data acquisition technologies
- Conduct more research on hybrid approaches including developing the best methods for combining data sources, developing weights, and determining the optimal number of static data collection systems per square mile of desired spatial coverage
- Add air quality sensors to environmental sensor stations
- Use connected vehicle data but supplement with additional data to capture gross emitters
- Leverage data and methodologies obtained and developed by the Michigan Test Bed and Safety Pilot Studies as well as the data and methodologies obtained and developed in the AERIS Broad Agency Agreement projects
- Confirm that more deployment and more data collection likely mean more granularity.

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Project Overview

The Applications for the Environment: Real-Time Information Synthesis (AERIS) State-of-the-Practice Support" project was conducted to assess the state-of-the-practice in travel behavioral and activity-based models, environmental models, and tools and technology available to enable environmental data acquisition. The output of the project will establish a foundation for the future research work to be conducted as a part of the AERIS program.

As shown in **Figure 1,** the three State-of-the-practice (SOP) reports in this foundational project will:

- Assess the capabilities of behavioral and activity-based models to assess how travel behaviors may be influenced by Intelligent Transportation Systems (ITS) implementation to reduce emissions from transportation system
- Explain the capabilities of environmental models to model emissions and their data requirements
- Identify technologies that will allow the capture of current data needed by emissions models and data needed to measure environmental impacts as well as capture current environmental data to enhance environmental databases for data, applications, and operations support.

The purpose of this report is to address the third bullet by documenting the state-of-the-practice scan of data acquisition technologies that are or will be used in implementing ITS strategies and AERIS Transformative Concepts.

There are two other SOP reports and seven Broad Agency Announcement research projects in Track 1 of the AERIS research plan. These reports are described further below in Section 1.2.3 Related Reports. These 12 reports are part of the foundational research phase of the AERIS program. They help to lay the foundation for additional AERIS efforts in Phases II and III of the program.

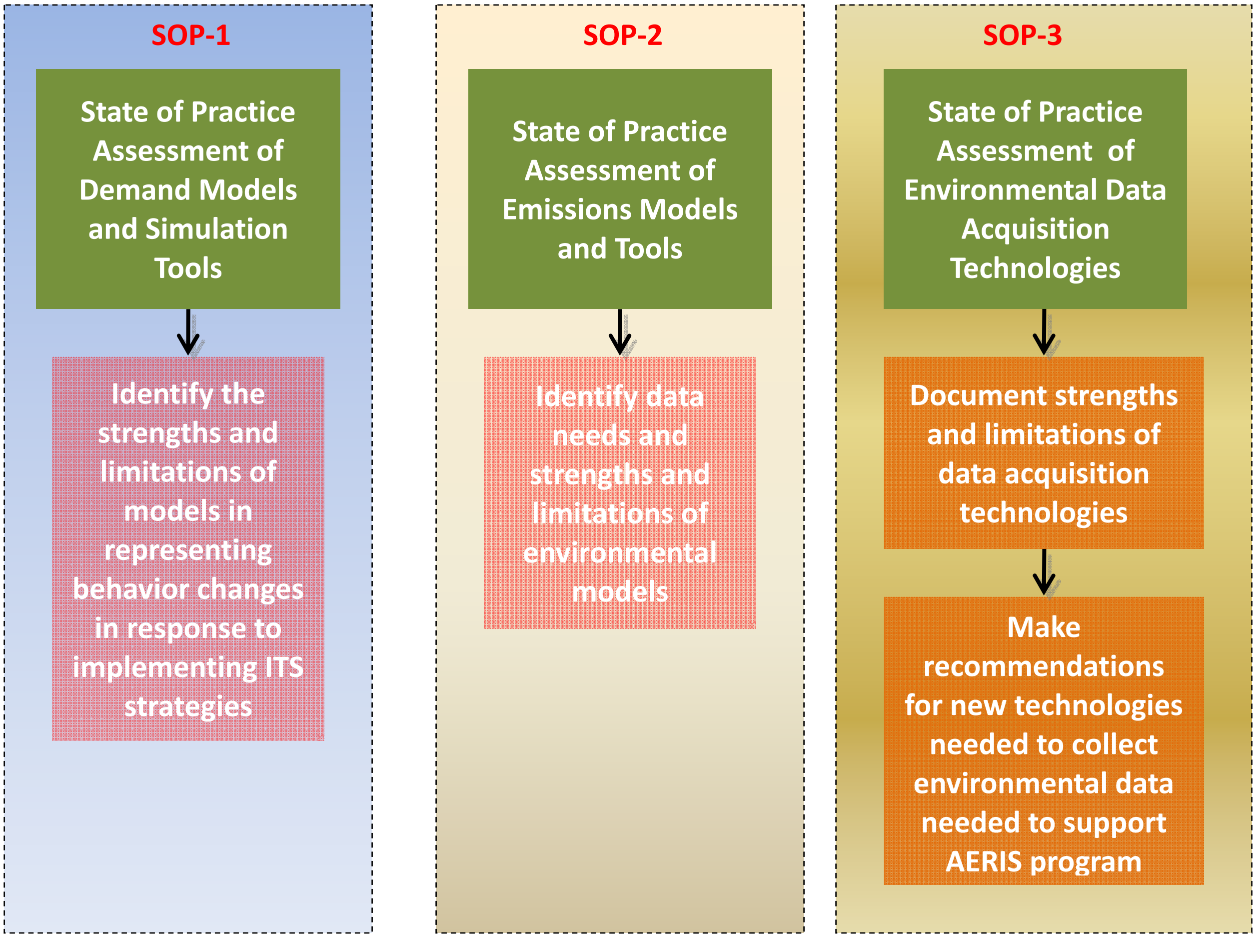

Figure 1: Descriptions of Three State-of-the-Practice Reports in this AERIS Foundational Research Project

Figure 2 shows how this project's activities and tasks, as well as traffic and emissions models, are inter-connected. It illustrates how the work presented here in this report relates to the work accomplished in the other projects. As the figure shows, input data to travel demand and activity-based models include the network data files (highway and transit files) and the trip generation data (land use characteristics, trip generation, and trip attraction rates, etc.). The travel demand models can be used to predict the changes to traveler choice in response to implementation of AERIS strategies such as eco-driving and congestion pricing. Outputs from the travel demand model include demand tables (trips by mode of travel and time of day). Traditional traffic assignment packages such as TransCAD or EMME can use the demand tables as the input and predict the route choice using volume delay curves. As the traffic assignment procedures in traditional models such as TransCAD or EMME do not predict the network performance associated with traffic operational improvements, traffic microsimulation tools such as VISSIM, Paramics, and DYNAMEQ are used to generate detailed link-by-link speed (second-by-second) and volume estimates. The environmental-related estimates are a function of the fleet mix (cars, light duty trucks, heavy duty trucks, etc.) as well as other parameters. Detailed link level speeds and volumes are then fed as inputs to emissions model such as MOVES or CMEM to estimate the emissions quantity. The emissions models use input parameters such as vehicle age distribution, fuel type use distribution, time of day, month of the year, and vehicle type mix in addition to the data generated by traffic simulation models.

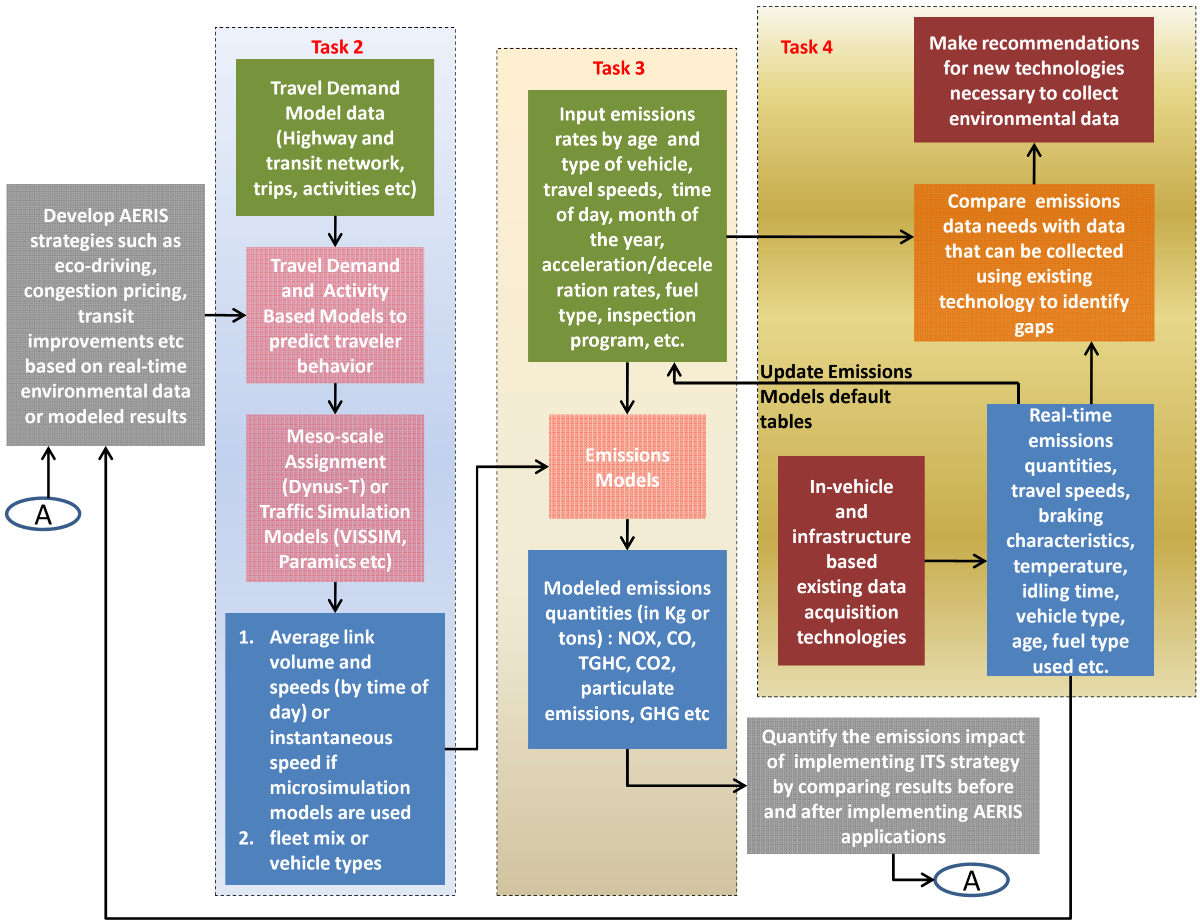

Figure 2: Project Tasks, Data Sources, and AERIS Applications

In addition, this report will identify the infrastructure and the vehicle-based sensors that are capable of collecting environmental data that can be either directly used to quantify environmental impacts or the data that can be used as input to emissions models to quantify air quality impacts. Figure 2 also shows that infrastructure and vehicle-based sensors can be used to collect real-time emissions data (CO_2, GHG, particulate, and others) directly before and after implementation of applications similar to the AERIS Transformative Concepts to quantify environmental impacts. Infrastructure and vehicle-based sensors can also be used to update vehicle type, driving characteristics, speed, weather data, etc. in the emissions models to predict the environmental impacts of applications. As part of this report, new technology that is needed if the existing technology is not capable of collecting the desired environmental data will be identified.

1.2 Report Overview

1.2.1 Sections of this Report

After providing definitions of the terms that will be used in the rest of the report in this section, this report will include the following sections. First, the environmental data needs of the demand and environmental models detailed in earlier project tasks in Section 2 will be discussed. Sections 3 and 4 will detail data acquisition technologies, first vehicle-based technologies and then infrastructure-based technologies. Section 5 describes hybrid data collection systems. Section 6 has two parts. The first part includes two summarizing tables: a comparison of the data acquisition technologies using several criteria and a mapping of the desired data elements with specific technologies. The second part is a discussion of recommendations for additional data acquisition technologies. References are provided in Section 7.

1.2.2 Terminology

In this subsection, definitions that apply to the terms used in this report are provided.

1.2.2.1 Data Acquisition Technologies

In this report the technologies that can be used to acquire environmental data are described. This data may be stand-alone environmental data or it may be data that can be used in the environmental models described in the analysis of environmental models report of this project and the travel demand and activity-based models report of this project. There are two fundamental types of technologies used to collect traffic and emissions data for environmental applications: those that employ sensors mounted in a vehicle, and thus that measure the specific emissions of that vehicle at all locations, but do not indicate emissions from other vehicles or overall air quality; and, and those that employ sensors that are mounted on external infrastructure, and indicate traffic and air emissions at a single point. The former type provide high-accuracy results for specific types of vehicles, and may be collected quite cost-effectively under a connected vehicle scenario, but require extensive work to produce a generalized result for a region, while the latter type provide high accuracy for one specific area, but likely cannot be generalized for or transferred to a different region. Using aggregated connected vehicle data to obtain a generalized result for a region may become easier as more vehicles become instrumented. But if a small number of vehicles are instrumented, then a generalized result may require assumptions about whether instrumented vehicles are representative of all vehicles and a required minimum density of instrumented vehicles for a desired confidence in the aggregated measure.

1.2.2.1.1 Vehicle-Based Technologies

In vehicle-based technologies, the primary sensors are carried on vehicles. As opposed to infrastructure-based technologies, which often do not store data, vehicle-based technologies store data, which then must be accessed via an infrastructure-based reader.

1.2.2.1.2 Infrastructure-Based Technologies

Infrastructure-based technologies utilize infrastructure-based readers or data acquisition systems, which can note emissions and other environmental-related data. Many infrastructure-based technologies do not store data locally but communicate them to remote units.

1.2.2.1.3 Connected Vehicle – Related Data Acquisition Technologies

There are three different types of data acquisition technologies under development in the connected vehicle U.S. Department of Transportation (USDOT) program. These include Here-I-Am Devices, Aftermarket Safety Devices, and On-Board Equipment. These are vehicle-mounted devices of increasing complexity that serve many of the same purposes and are mutually exclusive; vehicles will generally not have more than one of the three types of devices. Generally, Here-I-Am-Devices do not collect environmental data but they are described here for completeness. All of the connected vehicle devices collect data that may be used to calibrate or validate emissions models or models of the impacts of AERIS-related applications. Further description of these devices and the data collected by each is provided later in this report.

Connected Vehicle technologies have the potential to increase environmental data availability at little cost. Some connected vehicle technologies can provide engine data for individual vehicles. That data does not include direct measurements of the vehicle's emissions, but can be used to model the emissions of the vehicle.

1.2.2.1.4 Currently Available Technologies

With each technology, its prevalence and cost as well as other factors are discussed. A greater emphasis is put on the technologies that are most appropriate for collecting environmental data rather than on an attempt to be comprehensive and itemize all possible potential technologies.

1.2.2.1.5 Related ITS Standards

As part of the analysis of each technology, whether there are related ITS Standards is described. If there are standards for these technologies and whether some technologies or methods require proprietary approaches is described.

1.2.3 Related Reports

As described in Section 1.0, this is one of three AERIS Foundational Research State-of-the-Practice (SOP) reports prepared by Booz Allen Hamilton for the AERIS program. Noblis has written two other reports for the AERIS Foundational Research Program. One of these SOP reports is State-of-the-practice — Evaluation Techniques, which includes brief descriptions of vehicle and infrastructure-based data acquisition technologies in addition to an emphasis on summarizing environmental-related research reports. In contrast to the Noblis report, this report places more emphasis on the technologies rather than summarizing related research.

There are seven Broad Agency Agreement (BAA) projects that are also part of the Track 1 AERIS Research. One of these has been performed by MixonHill and Texas Transportation Institute. Their report describes data that can be used to evaluate AERIS applications. MixonHill drew on their experience with the Michigan Data Use, Analysis and Processing (DUAP) and Clarus projects. For another one of these projects, UC Riverside (UCR) and Calmar Telematics have done work showing how CAN bus data from trucks can be modeled into environmental data with their Comprehensive Modal Emissions Model (CMEM). In another

BAA project, UCR is investigating data collected from light vehicles to supplement the CMEM model. In this project, they are also investigating the use of Sensys Portable Emissions Modeling Systems detectors to supplement CMEM. Another project conducted by State University of New York at Buffalo is an evaluation of likely environmental benefits of lowest fuel consumption route guidance in the Buffalo-Niagara metropolitan area. Virginia Tech has two BAA projects including developing and evaluating intelligent eco-drive applications and developing connected vehicle eco-adaptive signalized intersection algorithms. Finally the Partners for Advanced Transit and Highways (PATH) Program at UC Berkeley is studying engaging the international community. These other reports and projects will be referenced in this report as appropriate.

2.0 DEMAND AND EMISSIONS MODEL DATA CONSIDERATIONS

Before describing specific data acquisition technologies in Sections 3 and 4 of this report, the environmental data utilized by demand and activity-based models and emissions models is described.

2.1 Data Needs Identified by the Other Reports

The reports prepared in other tasks of this project identify the data required by the models described in those reports. Table 1 presents the data required by the models.

2.1.1 From Task 2/SOP#1: Demand and Activity-Based Models

The second to last column in Table 1 presents the data required to calibrate traffic simulation models. Environmental data can be used to calibrate the traffic simulation models that are part of travel demand model systems by comparing model output with collected environmental data.

2.1.2 From Task 3/SOP#2: Emissions Models

Fundamentally, vehicular data can be used to model emissions of vehicles (individual mobile source emitters). Infrastructure-based data provides measurements of pollutants at one fixed location. Both vehicular data and infrastructure-based data alone are insufficient to calculate area-wide air quality. To calculate area-wide air quality, additional models are needed. Example emissions models include the MOVES model developed by the EPA, which is often used to calculate area-wide air quality from infrastructure-based data and the CMEM created by the University of California at Riverside's Center for Environmental Research Technology (UCR-CERT) often used to calculate individual vehicle emissions. Both of these models are described further in the Task 3/SOP#2 report. At the end of the Task 3/SOP#2 report, there is a section on environmental data needs. The last column in Table 1 presents the data required by emissions models.

2.2 Desired Data

The data desired from data acquisition technologies is described here. In the next subsection, the uses of the environmental data are presented. Table 1, which lists the data elements, provides the types of data acquisition technologies that can collect that data, and presents current assumptions about the data required by the models described in the other state-of-the-practice reports is presented.

2.2.1 Why Environmental Data Is Collected

There are several reasons to collect environmental data including the following:

- **Identifying suitable data collection methods:** Identifying suitable data collection methods is a goal here. Comparisons of connected vehicle technologies or other vehicle-based technologies with infrastructure-based sensors will be discussed. Environmental data collection may be an added benefit of connected vehicle technologies.

- **Data to Validate Emissions Models and to Calibrate Traffic Simulation Models:** The models described in the other two SOP reports can use environmental data for validation and calibration. The particular data used by these models is shown in Table 1.
- **Refine/ Optimize applications related to the AERIS Transformative Concepts**: Refining applications related to the AERIS Transformative Concepts can occur before or after the concept is implemented, or even in real-time. Demand models including traffic simulation models, emissions models, or both could be used to model the environmental, mobility, and safety impacts of the application related to the Transformative Concept. Using environmental data to refine and optimize applications related to AERIS Transformative Concepts is beyond the scope of the envisioned AERIS program and this report.
- **Model impacts of applications related to the AERIS Transformative Concepts:** The benefits of a specific environmental application and how it compares with other applications related to the AERIS Transformative Concepts is of interest. Demand models including traffic simulation or emissions models can be used to perform a cost/benefit analysis to make this comparison. Using environmental data to model the impacts of applications related to the AERIS Transformative Concepts is beyond the scope of the envisioned AERIS program and this report.

These bullets suggest that there are many reasons why environmental data is collected. The data collection and modeling may vary by application and by modeling purpose. For example, data on atmospheric conditions that will trigger a mitigating application may be collected. Or perhaps individual vehicles to determine whether they should be allowed in a low-emission zone are monitored. The next subsection describes the data that may be collected.

2.2.2 Potential Data Elements that May Be Collected

Table **1** presents a list of data elements. The checks in the columns indicate whether this technology can provide a measurement of that data element. Whether that data element is required for calibration of traffic simulation model output or in as emissions model input is indicated using an "R" or as a potentially supplemental data element is indicated with an "S". Supplemented data is not required as an input in a typical model, but may be used for calibration or validation. A more comprehensive table showing these data elements mapped to specific technologies is presented as a summary table in Section 6.1.

Table 1: Desired Environmental Data by Type, Name, and Availability by Vehicle-Based and Infrastructure-Based Technologies

Data Category	Environmental Data	Vehicle-Based	Infrastructure-Based	Used for Traffic Simulation Calibration	Used for Emissions Models Input
Pollution/ Emissions	Particulate Emissions/ Evaporative Emissions		√	S	R

Data Category	Environmental Data	Vehicle-Based	Infrastructure-Based	Used for Traffic Simulation Calibration	Used for Emissions Models Input
	Criteria Pollutants		√	S	R
	Carbon Monoxide	√	√	S	R
	Nitrous Oxide (NOx)				
	Greenhouse Gases/Hydrocarbons		√	S	R
Atmosphere/ Meteorology	Temperature	√	√		S
	Barometric Pressure	√	√		S
	Relative Humidity		√		S
	Precipitation	√	√		S
Road/Weather	Pavement Temperature		√		S
	Wind		√		S
Vehicle	Braking	√			S
	Engine Idling	√	√		S
	Engine Starts	√			S
	Tail-Pipe Emissions	√			R
	Vehicle Mileage	√			R
	Vehicle Fuel Type	√			S
	Time Spent Idling	√			S
	Idling Location	√			S
	Fuel Consumption	√		S	R
	Ambient Temperature	√			S
Traffic	Average Speed	√	√	R	R
	Instantaneous Speed	√	√	R	R
	Acceleration/ Deceleration Rates	√			S

An "R" in the Traffic Simulation Calibration or Emissions Model columns indicates that this is a Required data element for these models. An "S" indicates that this is a Supplemental data element.

3.0 VEHICLE-BASED DATA ACQUISITION TECHNOLOGIES

In this section, the commercially available vehicle-based data acquisition technologies and those under-development connected vehicle technologies are described. Their ability to collect environmental data is assessed. This includes describing the quality and usefulness of the environmental data generated by the technology. For each technology:

- The technology is described. The description includes how the technology can be used to acquire environmental data, including units of specific data elements used for environmental data
- Applicable vehicles (if appropriate) are provided
- Example deployment locations are provided
- Appropriate ITS Standards related to the technology are provided. If appropriate, whether proprietary approaches are required to access environmental data with these technologies is described
- At the end of this section, in Table 2 a rough estimate of the cost of collecting environmental data with the vehicle-based sensors is provided. This may include the cost of installing the technology.

Section 6, at the end of this report, includes a summary table (Table 3) that provides the following information related to all of the data acquisition technologies described in the report:

- Cost of data collection
- Difficulty of installation
- Potential spatial coverage
- Coverage of vehicle types
- 2016 penetration of vehicle population (if appropriate)
- Mobile data vs. static data
- Latency of data to final application
- Granularity.

Vehicle-based data acquisition technologies provide emissions-related data for specific vehicles. If area-wide measures of air quality are desired, then a model is required. To calculate area-wide air quality using only vehicular emissions, any collected vehicular data must be scaled to account for all vehicles (including vehicles not equipped with the technology) and to this must be added models that account for weather conditions and for the emissions of major point-source emitters.

3.1 Currently Available Technologies

In this section, a number of commercially available technologies are identified. These technologies include technologies related to the CAN bus on commercial vehicles (medium and heavy duty) and technologies related to the OBD II diagnostic system on other vehicles.

Portable Emissions Measurement Systems (PEMS) and Commercial Fleet Systems are also described.

There are two classes of commercially available vehicle-based technologies that can be used for environmental modeling:

1. Vehicle Data Reporting Technologies — technologies that report vehicular data that can be used to model vehicular emissions and/or that “flag” that there is an emissions-related concern. These include technologies that collect CAN bus data and OBD II data as well as commercial vehicle fleet data; and
2. Vehicle Emissions Measurement technologies—technologies including sensors that measure individual vehicle emissions. The primary member of this class is the PEMS.

For vehicle data reporting technologies — technologies that provide engine data such as OBD II or J1939 CAN bus information, how available engine status information can be used to support environmental models is explored. For example, engine run time and speed provide a basis for an engine emissions model, but more engine status information can greatly enhance the accuracy of environmental applications. Conducting an engine operation reduction study requires more than solely compiling the total time a vehicle is operating. The reasons for the idle / operating events are of great importance to understanding the requirements for the operation of each particular vehicle’s engine and to determining the best technical solutions for operation reduction in each application. Therefore, additional data elements are required to gain an understanding of the nature of vehicle operations.

Many variables of engine performance data are required to formulate a dataset that monitors the operational time of on-road vehicles and their corresponding fuel consumption. These variables include vehicle characteristics, operation type, and idling cause. These variables can be collected using a variety of existing sources on the vehicle including on-board communications networks, GPS receivers, and other existing sensors on the vehicle. No additional sensors need to be added to the vehicles.

This section also illustrates that connected vehicle devices may provide a new and inexpensive way to gather environmental data. Cost-effective, efficient gathering of environmental data can be a major contribution of vehicle to infrastructure (V2I) connected vehicle communications.

3.1.1 CAN Bus (Commercial Vehicles)

The Controller Area Network (CAN) bus is the primary vehicular bus, which distributes information among all control units in the vehicle (including the engine control unit, chassis/brake control unit, transmission control unit, and small control units such as airbag, dashboard, etc.). Although all private passenger vehicles built since electronic fuel injection became standard (roughly 25 years ago) have some form of CAN bus, there is no CAN bus standard for private vehicles—it is different for every manufacturer. However, there is a standard for commercial vehicles: SAE J1939 is the current CAN Bus standard. Older commercial vehicle CAN bus standards include SAE J1708 or SAE J1850.

Getting data from light vehicle CAN buses, as was done in USDOT's Vehicle Infrastructure Integration Proof of Concept project, generally requires cooperation of the manufacturer, i.e., the manufacturer must provide some form of electronic translation unit that sends CAN bus data to the OBE. Many connected vehicle researchers hope that On-Board Equipment (OBE) (Integrated Devices) installed by the auto manufacturers (original manufacture equipment) will have a CAN bus interface. Getting CAN bus data for light vehicles may be proprietary and not immediately possible without manufacturer cooperation and specific equipment. Most of this section concentrates on the use of CAN bus data for commercial vehicles since commercial vehicle readers are readily available for installation and access non-proprietary systems and data; however, the description of what is on the CAN bus and the technologies used to access the CAN bus may apply to light vehicles in the near future.

3.1.1.1 What Is on the CAN Bus

All major vehicle electronics systems communicate with each other on the CAN bus, except vehicle security systems (i.e., the ignition interlock, which prevents vehicle theft by electronically disabling the engine unless a valid key is present). Thus, the CAN bus contains data on headlight status, wiper status, driving pedal status, and other vehicle systems. More importantly for emissions, it contains engine data, including engine speed, intake air data, spark ignition data; oxygen sensor data (pre- and post-catalytic converter if available), modeled catalytic converter temperature, exhaust gas temperature, and exhaust gas recirculation data. For example, the CAN bus contains very specific data on engine states, such as indicating any one of 20 or more reasons why an engine switched to idle.

This data is distributed in groups called messages that are broadcast in many different packet frequencies. These frequencies vary by manufacturer, but in general most of the messages are updated every 100ms. Very uncritical values are included in messages updated less frequently (1s). Critical values like engine speed are updated faster (every 10 ms).

3.1.1.2 Example Technologies for Accessing the CAN Bus (EOBR)

CAN bus data can be recorded on Electronic On-Board Recorders (EOBR). Many EOBR that plug into J1939, J1708, J1850, and OBD II connectors and automatically store their data can be installed by the driver in less than 10 minutes. Some of these devices do not require any custom wires or hard- mounting provisions.

A wide variety of on-board devices are available; one example is the RouteTracker EOBR by Turnpike Global Technologies. Roughly the size of a cellular telephone, this unit mounts on the dashboard of the vehicle and includes both a GPS and a direct connection to the vehicle's onboard network (using the J1708, J1850, J1939, or OBD bus depending on the truck size and type). Like other

RouteTracker measures - 4.0" x 3.5" x 1.25" fleet tracking systems, RouteTracker captures vehicle location, a variety of engine status values, and continuous engine data such as speeds, acceleration, and RPM, transmission, and brake status information, including parameters that can be used to determine the location and duration of vehicle operations.[1] The unit can store up to 30 days of data onboard, and offloads data wirelessly via cellular telephone or fixed receiver. Installation can be performed relatively quickly by a non-technical user; the unit is mounted on the dashboard of the vehicle, and plugged into an existing data port to communicate with the onboard network. Connected vehicle technologies covered in a later section also allow CAN bus data to be collected.

There are some challenges in downloading the data frequently from individual vehicles and aggregating data from multiple vehicles as needed. Many current fleet systems send data over cellular networks. This may be costly (for example, $30/month per vehicle) and require the vehicle to be in areas with good cellular coverage. Other fleet systems store a limited number of hours of data until the vehicle is in a garage and the data can be accessed (either wirelessly or through a wire) but this does not provide real-time data. Once data is downloaded or sent through a cellular network, it likely requires processing before it can be used in an application. For example, determining that conditions are appropriate to initiate an emission-reducing strategy likely requires data from multiple vehicles to make sure that the reading from one vehicle is not an anomaly. Getting real-time data from vehicles over a non-stable cellular network may add to the complexities.

3.1.1.3 Modeling Emissions Based on CAN Bus Data

Engine data such as CAN bus data can be used to model the tailpipe emissions of individual vehicles. While this emissions-modeling research has been conducted by many researchers, the University of California at Riverside (UCR)'s Center for Environmental Research & Technology (CERT) has performed extensive research on modeling emissions based on engine data. UCR-CERT has created the Comprehensive Modal Emission Model (CMEM), a model that calculates the tailpipe emissions and fuel use based on engine data for an individual vehicle. A graphic showing the components of the CMEM model is shown in **Figure 3**.[2]

[1] XATA Turnpike, Inc. (2011). RouteTracker Product Overview. http://eobr.com/product_overview/index.php. (Accessed May 2, 2011).

[2] University of California at Riverside-Center for Environmental Research & Technology. (2011). CMEM-Model. http://www.cert.ucr.edu/cmem/model.html (accessed May 2, 2011).

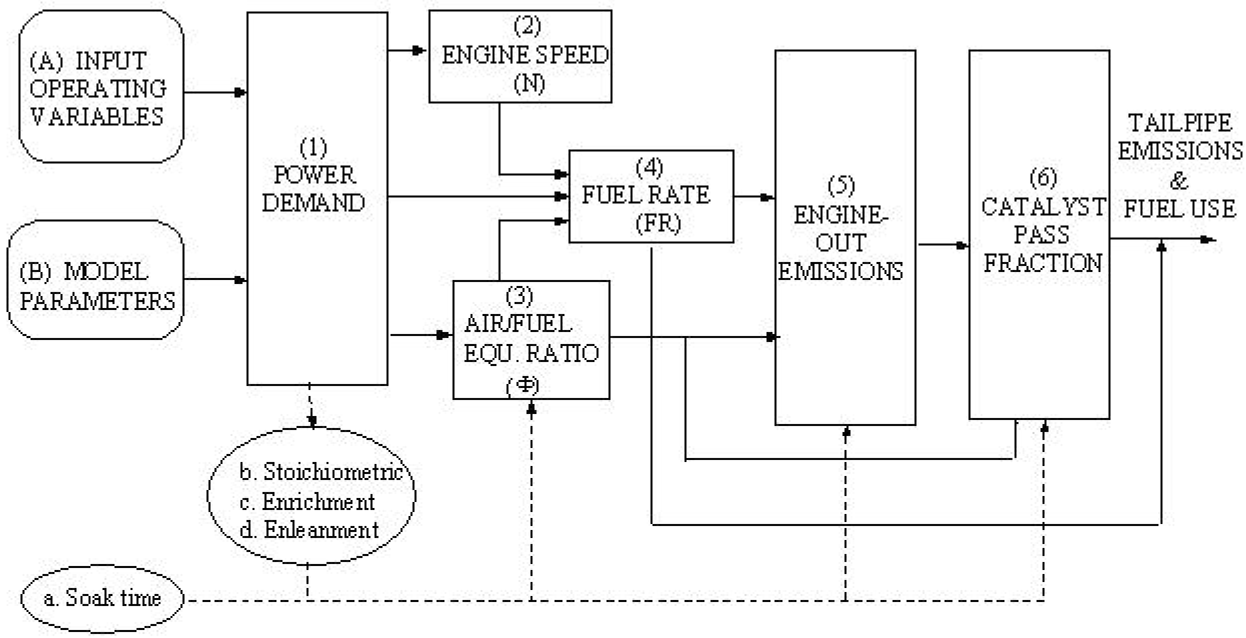

Figure 3: The CMEM model maintained by UCR-CERT

Leveraging the work on the CMEM model, UCR-CERT and Calmar Telematics are performing an AERIS Broad Agency Agreement project for FHWA which is a research project to model emissions from heavy vehicles using J1939 CAN bus information. The report discusses the CMEM and the mechanics of gathering data (specifically, the fact that some J1939 data is broadcast at regular intervals over the bus and some must be queried by other modules on the bus). [3]

UCR has provided Calmar Technologies with this list of engine data elements from the CAN bus that may be useful for feeding the model (box A above in the top left corner of Figure 3). Not all have been included in the CMEM model. UCR is still investigating which data elements will be useful and will issue a final report of their project in summer 2011.

- Engine Fuel Rate (Liter Per Hour)
- Diesel Particulate Filter Active Regeneration Status
- Particulate Trap 1 Soot Load Percent
- Aftertreatment Diesel Particulate Filter Outlet Gas Temp
- Aftertreatment Exhaust Gas Temperature (Furthest Upstream Sensor)
- Aftertreatment Exhaust Gas Temperature (Furthest Downstream Sensor)
- Exhaust Gas Temperature
- Engine Speed (Revolution Per Minute)

[3] University of California Riverside, Center for Environmental Research and Technology, and Calmar Telematics LLC. (2011), *Research on Intelligent Transportation System Application to Improve Environmental Performance, DRAFT TASK 1 REPORT*, 2011.

- Engine Percent Load At Current Speed
- Engine Intake Manifold Pressure
- Engine Intake Manifold Temperature
- Engine Fuel Temperature
- Actual Engine – Percent Torque
- Transmission Actual Gear Ratio
- Exhaust Gas Recirculation Valve position
- Ambient Air Temperature
- Engine Coolant Temperature.

After reviewing the latest version of the SAE J2735 ITS Standard, Calmar and UCR-CERT concluded that more emissions-relevant data should be considered in the next update of the standard. Currently, the only values in SAE J2735 related to emissions are the following:

- Data Element: DE_Acceleration
- Data Element: DE_AmbientAirTemperature
- Data Element: DE_J1939-71-Trailer Weight
- Data Element: DE_Speed
- Data Element: DE_ThrottlePosition
- Data Element: DE_VehicleMass
- Data Element: DE_VehicleType.[4]

In addition to engine data, vehicle path data (location / time / speed) data can also provide useful input to the model.

In addition to engine and vehicle data variables (box A in the upper left corner of Figure 3), the following engine parameters (box B shown on the left side of Figure 3) may be used to calibrate the model for specific vehicles. UCR is still investigating which data elements will be useful and will deliver a Final Report in summer 2011. These parameters include the following[5]:

- Engine displacement
- Engine idle RPM
- Maximum engine power
- Maximum engine torque
- Engine speed at maximum engine power
- Engine speed at maximum engine torque
- Fuel rate at idle
- Engine running load
- Engine friction factor
- Accessory load.

[4] University of California Riverside, Center for Environmental Research and Technology, and Calmar Telematics LLC. (2011), *Research on Intelligent Transportation System Application to Improve Environmental Performance, DRAFT TASK 2 REPORT,* 2011.

[5] *Ibid.*

3.1.2 OBD II

OBD II is a vehicular data output containing vehicle and diagnostic information. An OBD II port is included on all passenger vehicles in the U.S. since 1996 because of a California Air Resources Board (CARB) requirement. Outside the U.S., OBD II information has been required on vehicles in most major markets since 2000. The OBD II port is located inside all vehicles on the driver's side. OBD II data can be accessed using three major categories of devices:

- A specially designed diagnostic tester, commonly used at Vehicle Inspection Stations or mechanics' shops
- A laptop computer, connected to the port with a U.S.B-OBD II converter cable
- A dongle that plugs into the OBD II port and contains a Bluetooth transmitter, which wirelessly transmits the data to any device equipped with Bluetooth, typically a mobile phone.

OBD II is not a single standard but a group of six SAE standards including SAE J1962, SAE J1850, SAE J1978, SAE 1979, SAE 2012, and SAE J2178. The difference between the six standards is the physical connector and signal transmission protocol.

Each vehicle model and configuration may have slightly different information available on the OBD II port. That is because automotive manufacturers often choose to provide some additional diagnostic data on the OBD II port, beyond the minimum requirements, and the requirements themselves vary based on the precise vehicle / engine configuration.

OBD II data is used for remote diagnostics, and can be used in place of CAN bus data if CAN bus data is not accessible. Similar to the CAN bus, all vehicles collect OBD II data that can be accessed using a variety of onboard devices.

3.1.2.1 What Data Is on OBD II

OBD II data includes vehicle diagnostic data (error flags) and a small subset of the engine data available on the CAN bus. Diagnostic data available include the errors that California Air Resources Board (CARB) deems emissions relevant. These errors are typically diagnosed by the engine control unit based on the sensor data available to it. Errors include major engine failures such as overheating, loss of oil pressure, or an entire inactive cylinder to more minor engine failures, including an abnormally high number of misfires, a leak in the tailpipe, or even a leak in the gas cap.

The engine data available on OBD II includes basic engine running information. It is provided roughly in real-time, though latencies of 1s or more are possible. The typical engine data includes the following:

- Vehicle Speed (mph)
- Engine speed RPM (Revolutions per minute)
- Fuel consumption
- Air / Fuel Ratio
- Intake Air Pressure

- Throttle position
- External barometric pressure
- EVAP System vapor pressure
- Fuel trim
- Engine Load (calculated torque)
- Valve Timing Advance
- Battery Voltage
- Engine coolant temperature.

Like CAN bus data, OBD II data are not archived. They are provided in roughly real-time only (accounting for the latency of the OBD II port), and include recent data from the CAN bus (note that the diagnostic data is stored in the engine control unit's flash memory). Thus for data collection from OBD II ports, an external recorder must be present.

3.1.2.2 Example Technologies for Accessing OBD II (EOBR)

Electronic on-board recorders (EOBR) to plug into J1939, J1708, J1850, and OBD II connectors are available. Some of these can be installed by the driver in less than 10 minutes. Most of the devices do not require any custom wires or hard mounting provisions. Some of these are stand-alone devices from companies like Garmin (known for in-vehicle GPS routers), some can be bought at auto parts stores (or standard internet retailers like www.Amazon.com), and some use Smartphone applications. The technologies are ubiquitous but as with the CAN bus technologies, it is cumbersome to download the data frequently from individual vehicles. It can also be challenging to aggregate data from multiple vehicles, as needed, for inputs to emissions models. Many in the ITS community hope that connected vehicle technologies described in the next section will make the collection of OBD II and / or CAN bus data much more convenient.

While dedicated OBD II data recorders exist, a less expensive and more common way to access and record OBD II data is to use an OBD II kit available from the Internet. Such a kit typically includes a dongle that plugs into OBD II port (located on the driver's side in the vehicle cabin), which transmits the data wirelessly via Bluetooth to a Smartphone. Griffin Technologies' CarTrip is an example of such a system. The system includes the dongle and an iPhone application. The system is available for $90. [6] The CarTrip dongle and application are displayed in **Figure 4.**

[6] Griffin Technology. (2011). *CarTrip OBD-II Hardware Interface.* http://www.griffintechnology.com/cartrip?sms_ss=facebook&at_xt=4d9109f13084c945,0 (accessed May 2, 2011).

Figure 4: Example OBD II EOBR and Accompanying Smartphone Application

3.1.2.3 Using OBD II for Annual Emissions Testing

With the passage of California Assembly Bill 2289 (AB 2289), individual vehicle emissions testing will be performed using OBD II data. This is set to begin January 1, 2013. Model Year vehicles 2000 and later are no longer subject to tailpipe emissions tests. The plan is to reduce the time and cost of the annual smog check.[7]

3.1.3 Portable Emissions Measurement System (PEMS)

Portable Emissions Measurement Systems (PEMSs) are vehicle-mounted sensor arrays (with sensors typically mounted in the exhaust pipe) connected to a data archiving computer typically located in the passenger area (cockpit or cab) of the vehicle. The goal behind PEMS is that real-world measurement data is better than data measured in a lab because it captures on-road operating conditions rather than simulated conditions. In addition, PEMS system studies are often cheaper than emissions lab studies, and it is thus less expensive to get larger amounts of data using PEMS. PEMSs were developed in part to collect data that could be used in the Environmental Protection Agency's (EPA's) large-scale vehicle emissions model, the Motor Vehicle Emission Simulator (MOVES) model.[8] Two PEMSs are illustrated in **Figure 5.**

[7] Smogtips.com, "AB 2289—New Smog Check Law", found at http://www.smogtips.com/new-smog-law-AB-2289.cfm (accessed May 16, 2011).

[8] U.S. Environmental Protection Agency, Office of Transportation and Air Quality. (2005) *Assessment and Standards Division In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles.* http://epa.gov/otaq/regs/hd-hwy/inuse/420r05006.pdf (accessed May 2, 2011).

Figure 5: Two example PEMS systems from [9] and [10]

A 2005 EPA report found that PEMS units typically cost $100,000-180,000, and can have an annualized cost of around $34,000.[11] However, due to greater use of PEMS and the emergence of commercial products such as the Semtech DS, prices have dropped; still, it is likely that each PEMS unit will cost well over $10,000. In fact, a sales representative from Semtech was contacted and he said that the Semtech DS depicted in **Figure 6** costs $150,000 (fully featured) and that they will release the cheaper ECOSTAR system in the third quarter of 2011.[12] Thus PEMS remains a much more expensive manner of collecting data than CAN bus or OBD II data collection. However, the accuracy and reliability of PEMS data for tailpipe emissions is significantly higher.

Figure 6: Sensors, Inc.'s SEMTECH-DS PEMS Mobile Emission Analyzer[13]

[9] European Commission Joint Research Center Institute for Environment and Sustainability. (2010). *In-Use Emissions Testing and Portable Emissions Measurement Systems (PEMS).* http://ies.jrc.ec.europa.eu/eu-pems (accessed May 2, 2011).

[10] Sensors, Inc. (2011). *SEMTECH Product Line of Portable Emissions Measurement Systems (PEMS).* http://www.sensors-inc.com/onboard.html (accessed May 2, 2011).

[11] U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Assessment and Standards Division (2005). *In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles.* http://epa.gov/otaq/regs/hd-hwy/inuse/420r05006.pdf (accessed May 2, 2011).

[12] Email communication with Rob Wilson of Sensors, Inc. on May 2, 2011.

[13] Sensors, Inc. (2011). *SEMTECH Product Line of Portable Emissions Measurement System (PEMS).* http://www.sensors-inc.com/ds.html (accessed May 2, 2011).

PEMS data accuracy can be further increased by employing a hybrid approach that weights PEMS-measured emissions by a correction factor. To achieve this, a vehicle's emissions are measured simultaneously using a PEMS device and a fixed Remote Sensing Device. The differences between the emissions measurements using the two measuring technologies are taken as correction factors. Then, the field data collection continues, using only PEMS measurements. Finally, the PEMS measurements are weighted by the correction factors. This method allows PEMS data, which for cost reasons is always collected with a relatively small number of vehicles, to accurately reflect collection from a larger fleet of vehicles.[14]

3.1.4 Commercial Vehicle Fleet Hardware

Many of the largest interstate trucking fleets install fleet tracking and communication devices in their vehicles. These units track vehicle position using the global positioning system (GPS) and connect to on-board diagnostic systems to collect status information on a variety of vehicle components, including engine, transmission, brakes, and accessories. This data is similar to the data from CAN bus but transmitted regularly. Data is transmitted wirelessly from each truck to a service provider where it is processed into reports for review by fleet operators. Some level of data processing is required by the application service provider to isolate parameters that are relevant to environmental applications such as vehicle location, vehicle speed, engine speed, parking brake position, and accessories on / off status and to remove identifiers (such as the name of a fleet or individual operator) that, if disclosed, would violate users' privacy.

Data for Class 2b – 8 trucks (including regional haul, local delivery, and vocational trucks) could be obtained by installing a low-cost vehicle tracking system. There is the possibility of obtaining data for this segment of trucks from application service providers as well; some of these vehicles are already equipped with electronic on-board recorders (EOBRs) or tracking systems from smaller application service providers. However, these types of systems generally are used only by larger fleets and, in particular, applications such as local delivery. To obtain a wider sample of vehicle behavior, vehicles could be instrumented that do not currently have EOBRs, effectively extending the "reach" of electronic data collection to virtually any truck operating in the United States.

3.2 Connected Vehicle Technologies

Connected vehicle technologies include both vehicle-to-vehicle (V2V) technologies that allow vehicles to communicate with other vehicles and vehicle-to-infrastructure (V2I) technologies that allow vehicles to communicate with communications infrastructure via a number of different wireless broadband technologies.

Connected vehicle technologies generally include vehicle hardware that can execute various applications and perform various tasks. One task is to provide data. Connected vehicle technologies generally provide vehicle location/speed information as well as some vehicle engine status information (from the OBD II or the CAN bus). Using connected vehicle technologies, each vehicle can act as a "data probe," collecting environmental vehicle

[14] For example, Koupal, John, "Portable Emission Measurement—U.S. EPA Perspective" presented at the PEMS Conference March 24, 2011 found at: http://www.cert.ucr.edu/events/pems2011/01_John%20Koupal.pdf (accessed May 16, 2011).

speed/location information and engine information (if available), and transmitting it back to the infrastructure. By acting as a probe, connected vehicle technologies will collect data to support environmental models. Because the infrastructure for collecting the data will be deployed for safety and mobility applications, the marginal cost of collecting additional data with them is very low. Thus, connected vehicles may provide a new, cost-effective way of gathering environmental data. This is an important added benefit of V2I communications infrastructure deployment.

Connected vehicle technologies are still being developed. The USDOT is supporting the development of these technologies. As of now, they have no market penetration. Connected vehicle technology has been deployed at the Michigan Test Bed and, more recently, in Florida, California, and New York. The technologies will be studied in greater detail in upcoming demonstrations including the USDOT's upcoming safety pilot.

There are three basic categories of in-vehicle connected vehicle devices. In increasing order of complexity, they are the following: Here-I-Am devices, Aftermarket Safety Devices, and On-Board equipment. These three are generally exclusive — there is no reason to have more than one of these devices in a vehicle.

One of the main benefits of Connected Vehicle technologies to improve environmental conditions is the potential to reduce the number of so-called super-emitters — vehicles that emit vastly more emissions than normal functioning vehicles. Some studies have found that roughly 30 percent of hydrocarbon and carbon monoxide emissions in some regions come from less than 1 percent of vehicles—the super-emitters.[15] Some super-emitters are vehicles not subject to emissions regulations such as antique vehicles. Other super-emitters are drivers who continue to drive when their "check engine" lights are on. Connected vehicle technologies have the potential to reduce the number of people in the latter category.

All connected vehicle devices include an exterior-mounted antenna and an in-vehicle unit.

3.2.1 Here-I-Am Devices

The simplest type of connected vehicle device is a Here-I-Am device. Here-I-Am (HIA) devices contain a GPS to measure vehicle location/speed/heading, and a DSRC radio to transmit a basic safety message. HIA devices broadcast Part 1 of the SAE J2735 Basic Safety Message (BSM) — a message containing the vehicle's dimensions, speed, heading, brake status, and heading. Using the language from the Safety Pilot SOW, this is "An aftermarket electronic device installed in a vehicle without connection to vehicle systems that is capable of sending the "basic safety message" over a Dedicated Short Range Communication (DSRC) 5.9 GHz wireless communications link. HIA devices do not run safety applications that issue audible or visual warnings to drivers. The HIA device will have internal permanent storage capability." It does not include a Human Machine Interface (HMI), and thus may not be capable of executing safety applications. It will be used for research purposes, to economically create a large fleet of vehicles to transmit safety messages in order to study safety messaging with a large population

---

[15] Bishop et al., *On-Road Motor Vehicle Emissions Including Ammonia, Sulfur Dioxide, and Nitrogen Dioxide.* http://www.arb.ca.gov/research/seminars/bishop/bishop.pdf (accessed May 16, 2011).

of equipped vehicles. This will be done in the USDOT's safety pilot. Here-I-Am devices are unlikely to be a final consumer product — the cost is likely not worth the value of the product and it has minimal benefits for environmental purposes. The device is described here to provide comprehensive descriptions of connected vehicle technologies and their potential application to collecting environmental data; however, beyond the location of the vehicle, you cannot get environmental data from Here-I-Am devices.

3.2.2 Aftermarket Safety Devices

Aftermarket safety devices (ASDs) include all contents of the Here-I-AM devices, but also have the ability to receive incoming messages via DSRC, and an HMI to indicate the outcome of safety applications to the driver. Using the language from the Safety Pilot SOW for ASDs: "An aftermarket automotive grade electronic device installed in a vehicle that is capable of sending and receiving the safety messages, as defined in Society of Automotive Engineers (SAE) standard J2735, Dedicated Short Range Communications (DSRC) Message Set Dictionary, version 2009-11, over a Dedicated Short Range Communication (DSRC) 5.9 GHz wireless communications link. The device has a working HMI; runs V2V and V2I Safety Pilot applications; and issues audible or visual warnings and/or alerts to the driver of the vehicle in which it is installed; and has internal permanent storage capability." The HMI may be simple — maybe just a display only — though it may include the possibility of driver input. ASDs will be capable of executing safety applications and will likely provide data related to both mobility and environmental applications. ASDs may also have additional wireless broadband capabilities beyond DSRC, such as the ability to communicate with cellular telephone networks. ASDs use a temporary power source, such as a battery or a plug into a vehicle's cigarette lighter.

Unlike Here-I-Am devices, ASDs are likely to eventually become consumer products. ASDs will be studied in the safety pilot as well. ASDs are likely to be among the earliest connected vehicle technologies available to consumers and also vital for phase-in of connected vehicle technologies as they are aftermarket devices, they can be installed by vehicle drivers quickly and easily, and thus have the potential to increase the population of equipped vehicles more rapidly than devices that require a mechanic to install or devices that must be included in the vehicle's original equipment. ASDs may have an OBD II interface (probably via Bluetooth dongle), and for commercial vehicles could even have a CAN interface. It is unlikely that ASDs for private vehicles will have a CAN-bus interface as the CAN bus is not accessible for aftermarket installation on private vehicles, and even if it were, the CAN bus is proprietary on private vehicles. ASDs can be used to acquire environmental data by combining vehicle location / speed data with whatever engine data is available (e.g., from the OBD II port).

3.2.3 Retrofit Devices and Integrated Devices (formerly On-board Equipment)

The most-sophisticated vehicle-based devices used for V2V and V2I connected vehicle safety applications are Retrofit Devices (installed on older vehicles by professional mechanics) and Integrated Devices (installed when the vehicle is manufactured). The following text uses the definitions from the Safety Pilot SOW.

A Retrofit Device is "An electronic device installed in vehicles, by representatives of the vehicle's OEM or by an authorized service provider, at a service facility after the vehicle has completed the manufacturing process (retrofit). This type of device is connected to proprietary data ports and can provide highly accurate information from in-vehicle sensors. The integrated device has a working HMI, both broadcasts and receives SAE J2735 messages, and can process the content of received messages to provide warnings and/or alerts to the driver of the vehicle in which it is installed."

An Integrated Device is "An electronic device inserted into vehicles during vehicle production at an original equipment manufacturer's (OEM's) factory. This type of device is connected to proprietary data ports and can provide highly accurate information from in-vehicle sensors. The integrated device has a working HMI, both broadcasts and receives SAE J2735 messages, and can process the content of received messages to provide warnings and/or alerts to the driver of the vehicle in which it is installed."

These devices contain all of the components of an ASD, and also have a permanent power source (connection to a vehicle's electrical system) and a fixed mounting in the vehicle cabin. They may have a CAN bus interface, though Retrofit Devices for light vehicles may have an OBD II interface instead of a CAN bus interface if the vehicle manufacturer wants to keep the CAN bus information proprietary. These devices will likely have an HMI that allows for driver input as well as display of information. Data transmission from both Retrofit and Integrated Devices will likely include both DSRC and other forms of wireless broadband. Retrofit Devices may appear on the market shortly after a decision to deploy connected vehicle technology is made in 2013; however, it is unlikely that Integrated Devices will appear on the market for at least 3 years after the decision is made (2016 or later) due to the time it takes for auto manufacturers to introduce new equipment. Because Retrofit Devices for private vehicles are unlikely to include CAN bus information, it is unlikely that CAN bus data from light vehicles will be available until 2016 or later, and then starting from 0 penetration in 2016, gradually phase in after that. For the next 5 years, OBD II information is the only information that will be available from light vehicles, supplemented with CAN bus information from commercial vehicles.

3.3 Cost of Technologies (Per vehicle)

The total cost of gathering environmental data from vehicles varies widely, depending on the level of infrastructure installed, the type of sensors employed, the length of the study period, the number of vehicles involved, and many other factors. **Table 2** describes the basic data collection scenarios from least to most expensive price per vehicle.

Table 2: Relative Cost of Different Vehicle-Based Technologies

Vehicle Data Collection Scenario	Environmental Data Acquisition Technologies	Cost Factors	Approximate Per-vehicle Price Range
Connected vehicle technologies (HIA, ASDs, and Retrofit and Integrated Devices) after vehicle to infrastructure (V2I) deployed	Data collection with opt-in application, on-board units (OBUs) with OBD II interface (for light vehicles), net-connected data archiving system	Bandwidth for data uploads if by broadband; data archiving	$0-$100
Vehicle data recording	Dedicated data recording	OBUs + data archiving	$100-$1000

Vehicle Data Collection Scenario	Environmental Data Acquisition Technologies	Cost Factors	Approximate Per-vehicle Price Range
technologies without connected vehicle technologies such as current fleet systems or systems that utilize individual electronic on-board recorders (EOBR)	OBUs with CAN Bus/OBD II interface*, data archiving system	system +manual uploading to data archiving system	
Connected vehicle technologies (HIA, ASDs, Retrofit and Integrated Devices) before V2I infrastructure deployed	As # 1, plus roadside data collection infrastructure, OBUs with CAN Bus/OBD II interface*	Same as #1 + roadside units	$500-$5,000
PEMS	PEMS data vehicle collection units, data archiving system	PEMS measurement units in every vehicle; manual uploading to data archiving system	$10,000-$100,000

*Smartphone's with EOBR applications generally do not have enough memory to serve this purpose. Note that many factors can affect price, so actual prices could be higher or lower than those listed here.

4.0 CURRENTLY AVAILABLE INFRASTRUCTURE-BASED TECHNOLOGIES

This section of the report includes infrastructure-based environmental data acquisition technologies that include remote sensing devices, air quality monitoring stations, and environmental sensor stations.

For the commercially available infrastructure-based technologies listed below, their usefulness for acquiring environmental data by describing the quality and usefulness of the environmental data generated by the technology is determined. For each technology:

- The technology is described. The description includes how the technology can be used to acquire environmental data, including units of specific data elements used for environmental data
- Applicable vehicles (if appropriate) are provided
- Example deployment locations are provided;
- Potential installation costs are provided if available
- Appropriate ITS Standards related to the technology are provided. If appropriate, whether proprietary approaches are required to access environmental data with these technologies is described.

Section 6, at the end of this report, includes a summary table (Table 3) that provides the following information related to all of the data acquisition technologies described in the report:

- Cost of data collection
- Difficulty of installation

- Potential spatial coverage
- Coverage of vehicle types
- 2016 penetration of vehicle population (if appropriate)
- Mobile data vs. static data
- Latency of data to final application
- Granularity.

4.1 Remote Sensing Devices

Remote sensing devices are used to monitor the emissions from passing vehicles. They are able to capture gross emitters (a function of vehicle age and maintenance) using an infrared beam. By placing an infrared (IR) light transmitter on one side of the road and aiming its beam into an IR receiver on the other side, when a vehicle drives through the beam, the computer compares the wavelength of the light after it passes through the exhaust plume to the wavelength of the normal IR light. It then calculates the percentage of hydrocarbons (HC), oxides of nitrogen (NOx), carbon dioxide (CO2), and carbon monoxide (CO). [16] This same source suggests that Remote Sensing Devices cost $90,000 to install in a permanent location and $140,000 as a mobile unit. **Figure 7** provides a diagram of an example of the Remote Sensing Device system.

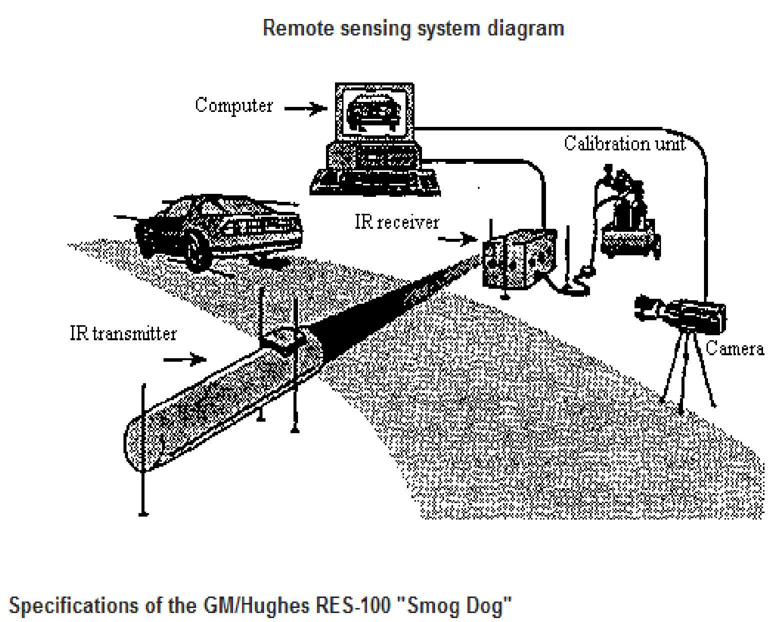

Figure 7: GM Hughes "Smog Dog" Remote Sensing System[17]

[16] National Motorists Association, "How Remote Sensing Works," found at http://www.motorists.org/emissions/remote-sensing (accessed May 16, 2011).

[17] *Ibid.*

Remote Sensing Systems have been used in California. A current system, depicted in **Figure 8**, is intended to test a total of one million vehicles at one-hundred sites in four California counties. This is supposed to constitute 10 percent of the area's vehicles. The test locations will be rotated and unannounced. During the 3-second test (many of the systems will be placed on freeway on-ramps), the license plate of vehicles with emissions above desired thresholds will be captured and owners will receive letters requesting repair. Some repairs may be subsidized.[18]

The developer of the first Remote Sensing System, Dr. Donald Stedman at the University of Denver, is involved in further tests of the system. A recent article published with Gary Bishop and Allison Peddle in the journal, Environmental Science and Technology, describes on road emission measurements of reactive nitrogen compounds from San Jose, Fresno, and West Los Angeles during March 2008. From measurements at these three sites, the researchers were able to estimate a national measurement of ammonia (NH_3) emissions, which have a strong dependence on model year and vehicle power.[19]

[18] Smogtips.com, "Roadside Emissions and Remote Smog Test Checkpoints" found at http://www.smogtips.com/remote_sensing.cfm (accessed May 16, 2011).

[19] Bishop, Gary, Allison Peddle, and Donald Stedman, "On-Road Emission Measurements of Reactive Nitrogen Compounds from Three California Cities," *Environmental Science & Technology*, American Chemical Society, April 9, 2010, Volume 44(9), pp. 3616-3620.

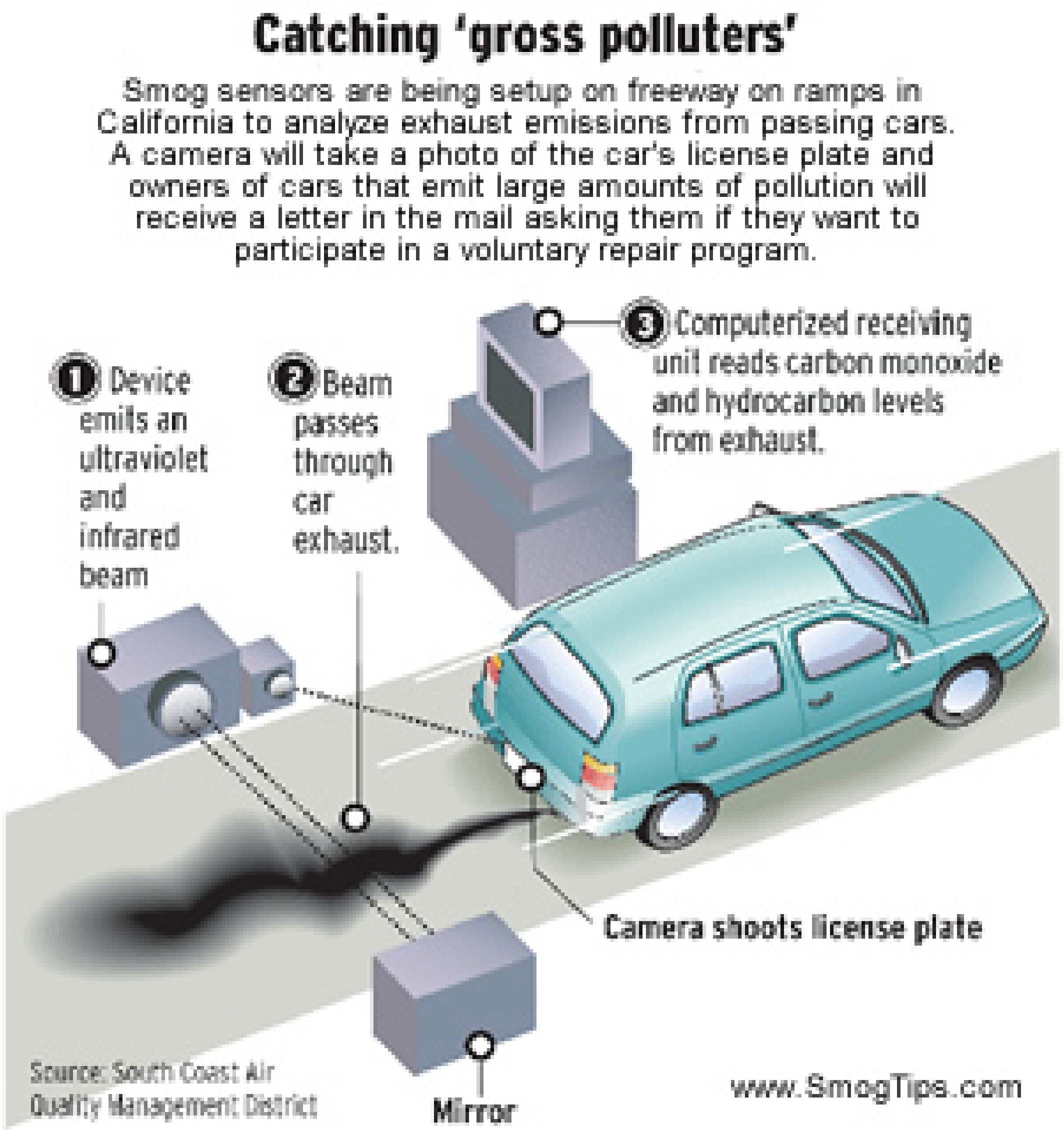

Figure 8: Example Implementation of Remote Sensing Device System[20]

Most Remote Sensing Systems are installed on single-lane roads such as a freeway on-ramp to ensure that the correct "high emitter" is identified. This may be considered a limitation of the technology; however, data from all passing vehicles is obtained. There is likely a correlation between high emitting vehicles and vehicles that are not equipped with connected vehicle devices or EOBR-reading devices. Thus RSDs may be valuable for collecting environmental data even when a large percentage of vehicles are instrumented with connected vehicle devices.

[20] Smogtips.com, "Roadside Emissions and Remote Smog Test Checkpoints," found at http://www.smogtips.com/remote_sensing.cfm (accessed May 16, 2011).

4.2 Air Quality Monitoring Stations

EPA maintains air quality monitoring stations across the country. These are generally used in non-attainment areas and aggregate airborne data over 8-hour or 24-hour periods. One method that allows for measurement of air pollutant emissions from area sources are optical remote sensing source measurement methods including Vertical and Horizontal Radial Plume Mapping (VRPM and HRPM). [21],[22] These methods use multiple-beam, scanning, optical remote sensing (ORS) instrumentation such as open-path Fourier transform infrared spectroscopy, ultraviolet differential absorption spectroscopy, open-path tunable diode spectroscopy, and open-path tunable diode laser absorption spectroscopy in unique radial configurations and optimization algorithms to provide essential spatial data for emission calculations.[23] These methods are often used to identify the specific emissions of stationary sources such as factory smokestacks and landfill gas emissions and not mobile sources.

4.3 Environmental Sensor Stations

An Environmental Sensor Station (ESS) is a fixed roadway location with one or more sensors measuring atmospheric, surface (i.e., pavement and soil), and / or hydrologic (i.e., water level) conditions. An ESS is a collection of devices used to measure environmental and/or weather conditions. ESS are often used as part of a Road Weather Information Station (RWIS). [24] There is a National Transportation Communications for ITS Protocol (NTCIP) ITS Standard for Environmental Sensor Stations (NTCIP 1204). The ITS Standard includes data elements for air quality measurements including carbon monoxide, carbon dioxide, nitrous oxide, nitrogen dioxide, sulfur dioxide, ozone, particulate matter, and an air quality block object. To conform with the ITS Standard, the ESS shall support at least one sensor to measure each of these air quality elements[25], but many ESS in the field do not include sensors that measure air quality emissions. Each ESS (without emissions sensors) costs approximately $50,000.[26]

---

[21] EPA, *Clean Air Research Science Products*, found at: http://www.epa.gov/airscience/products.htm (accessed May 16, 2011).

[22] EPA Technology Transfer Network Emission Measurement Center found at: http://www.epa.gov/ttn/emc/prelim.html (accessed May 16, 2011).

[23] ARCADIS G&M, Inc. "Evaluation of Fugitive Emissions Using Ground-Based Optical Remote Sensing Technology," 2007, found at http://www.epa.gov/nrmrl/pubs/600r07032/600r07032.pdf (accessed Jun 20, 2011).

[24] For example, RITA ITS Cost Database entry, "Maryland State Highway Administration estimated fog warning system addition to existing environmental sensor stations near Big Savage Mountain, Maryland cost $75,000" found at: http://www.itscosts.its.dot.gov/its/benecost.nsf/ID/D7E73D3356D8CD0185256FD4004A1104?OpenDocument&Query=CApp (accessed May 16, 2011).

[25] *NTCIP ITS Standard 1204*, November 2009, pages 44-45.

[26] RITA ITS Costs Database, "Detailed costs of road weather information systems deployed at several sites north of Spokane, WA" found at: http://www.itscosts.its.dot.gov/its/benecost.nsf/ID/D9FDC51609AAD49085256EC90059ED7E?OpenDocument&Query=CApp (accessed May 16, 2011) and Eric Gibbons, "Urban NTCIP Road Sensor Station Applications" found at: http://www.highsierraelectronics.com/misc_PDF/RoadSensorStationPaper.pdf (accessed May 16, 2011).

A graphic of an ESS is presented in **Figure 9**. This graphic, distributed by the FHWA Road Weather Management Program, includes several types of sensors but no emissions sensors. Given the source, this is likely typical of a general ITS installation of an ESS.

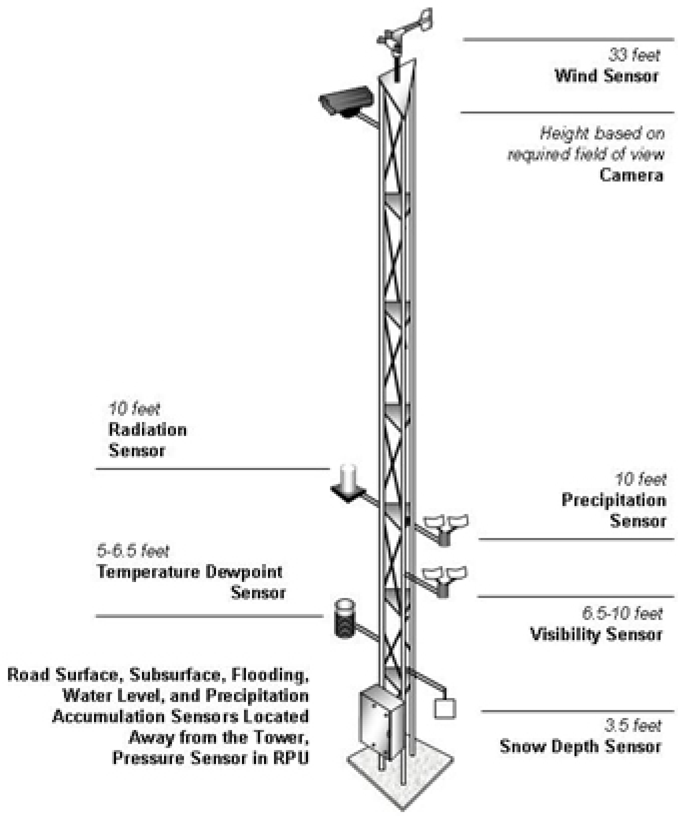

Figure 9: Environmental Sensor Station[27]

In 2004, the latest date for which there are ITS deployment statistics, 36 states used a total of 1407 ESS stations. [28] How many of these had sensors that obtained emissions measures are unknown.

4.4 Other Infrastructure-Based Technologies

The Noblis report also prepared as part of the foundational research of the AERIS program, "State-of-the-practice of Techniques for Evaluating the Environmental Impacts of ITS Deployment" provides a summary of three articles related to environmental data acquisition

[27] FHWA Road Weather Management Program, "Interactive Environmental Sensor Station" found at: http://www.ops.fhwa.dot.gov/weather/mitigating_impacts/interactive_ess.htm (accessed May 16, 2011).

[28] RITA Deployment Statistics Database, "ESS Deployment" found at: http://www.itsdeployment.its.dot.gov/ResultsStateNational.asp?ID=1152&year=2004 (accessed May 16, 2011).

from Infrastructure-Based Technologies.[29] The Noblis report describes Telvent's TRACE tool that utilizes traffic data and air quality measurements. A Google search and a search on the Telvent website have not provided more information about this tool beyond what is in the report. The second paper describes the use of microsimulation to model the impacts of mobile and static traffic and air quality measurements. The third paper describes a quadratic function regression curve to model emissions given vehicle speed and local conditions such as wind and terrain. The brief summaries suggest that the three articles describe data acquisition techniques but not technologies. The entries in this report emphasize technologies and not techniques.

[29] Glassco, Richard, et al. "State-of-the-practice of Techniques for Evaluating the Environmental Impacts of ITS Deployment", December 2010.

5.0 HYBRID INFRASTRUCTURE AND VEHICULAR DATA COLLECTION

More accurate emissions measurements may be obtainable by combining vehicle-based data with infrastructure-based data. In such a hybrid model, test vehicles drive by Roadside Sensing Devices (RSDs) at various speeds and under various conditions. Their emissions are both determined from the vehicular data (from PEMS or EOBRs connected to OBD II or the CAN bus) and measured by the RSDs. The ratio of the emissions determined from vehicular data to their RSD-measured emissions is then used as a scale factor on all further vehicular data collected. While such hybrid models have thus far been used in PEMS-related models[30], such a hybrid approach can also be used to improve the accuracy of emissions modeled from connected vehicle data.

30 For example, Koupal, John, "Portable Emission Measurement—U.S. EPA Perspective" presented at the PEMS Conference March 24, 2011 found at: http://www.cert.ucr.edu/events/pems2011/01_John%20Koupal.pdf (accessed May 16, 2011).

6.0 SUMMARY TABLES AND RECOMMENDATIONS

6.1 Matrix of Data Acquisition Technologies and Preferred Criteria

The technologies are described using several criteria in **Table 3**. These criteria include cost of data collection, difficulty of installation, potential spatial coverage, coverage of vehicle types, 2016 penetration of vehicles, mobile vs. static, direct emission measurement, and granularity. Most of the cells in the table include 1 to 5 ratings for these criteria according to the legend provided below the table.

Table 3: Mapping of Data Acquisition Technologies and Preferred Criteria

Technology	Criteria							
	Cost of Data collection	Difficulty of Installation	Potential spatial coverage	Coverage of Vehicle Types	2016 Penetration of Vehicle Pop.	Mobile Data vs. Static Data	Direct emission measurement	Granularity
OBD II + Engine On-Board Recorder (EOBR)	5	3	4	4	1	M	3	4
CAN Bus + EOBR	5	3	4	2	1	M	3	4
Here-I-Am + Connected Vehicle infrastructure	5	4	4	5	1	M	1	4
Aftermarket Safety Device+ Connected Vehicle infrastructure	4	3	4	4	3	M	1	4
Retrofit or Integrated Devices+ Connected Vehicle infrastructure	3	5	4	2	2	M	1	4
Portable Emissions Measurement System--PEMS	1	3	4	4	1	M	5	5
Fleet-Based Systems	3	2	4	1	2	M	3	3
Remote Sensing Devices (RSDs)	2	4	1	5	5	S	4	4
Air Quality Monitoring Stations	4	3	2	N/A	N/A	S	3	1
Environmental Sensor Stations	4	3	2	N/A	N/A	S	4	1
Hybrid Approach—PEMS and RSDs	1	3	4	2	3	B	4	5
Hybrid Approach—Connected Vehicles and RSDs	2	3	5	4	4	B	4	5

Notes: Most cells include a 1 to 5 rating of how well the technology fits the criteria. The following legend explains the meanings of the range of numbers or the letters provided in each column. N/A in a cell means the criteria is Not Applicable for that technology.
Cost: 1 is High (for example, $100,000 per vehicle); 2 represents a high cost of sensor, but it is used to collect data from multiple vehicles; 3 is $500-$1000 per vehicle; 4 is $100-$500 per vehicle; 5 is Low (less than $100 per vehicle).
Difficulty of Installation: 1 is Difficult (requires professionals to install and calibration); 3 (professional installation; minor calibration); 5 is Easy (factory-installed; no calibration).

Potential Spatial Coverage: 1 is Less (coverage of individual vehicles at only one point); 2 may be an aggregate of vehicles but mostly at a point; 4 is Coverage on all types of roads and over a large spatial area but not including all vehicles; and 5 is Coverage on all types of roads over a large spatial area aggregated for multiple vehicles.
Coverage of Vehicle Types: 1 is fewer types (only commercial vehicles or fleet vehicles or automobiles); 5 includes all vehicle types.
2016 Penetration of Vehicle Pop: 1 = specially equipped test vehicles only; 2 = present in few U.S. vehicles; 3= present in some U.S. vehicles; 4= present in many U.S. vehicles; 5= present in all U.S. vehicles.
Mobile Data vs. Static Data: M= Mobile, S= Static, B=Both.
Direct Emission Measurement: 1 individual emission data is not obtained; 4 emission data is obtained by not from individual vehicles; 5 direct tailpipe emissions are obtained from individual vehicles.
Granularity: 1 is Coarse (not possible to identify individual vehicles); 5 is Granular (data is obtained from individual vehicles).

6.2 Matrix of Data Elements and Specific Technologies

Table 4 provides a mapping of the data elements presented in Table 1 and all of the specific data acquisition technologies described in the report.

Table 4: Environmental Data Elements Mapped to Specific Data Acquisition Technologies

Data Element	Technology											
	Vehicle Data Sources		Connected Vehicle Technologies			PEMS	Fleets	Infrastructure-based Technologies			Hybrid Approaches	
	CAN Bus	OBD II	Retrofit and Integrated Devices	After-Market Safety Device	Here I Am	PEMS	Fleet-Based Systems	Remote Sensing Devices (RSDs)	Air Quality Monitoring Stations	Environmental Sensor Stations	Hybrid Approach – PEMS and RSDs	Hybrid Approach – Connected Vehicles and RSDs
Particulate Emissions/Evaporative Emissions	X	X	X				X	I	I	P	I	I
Criteria Pollutants	X	X	X				X	I	I	P	I	I
Carbon Monoxide	X	X	X				X	I	I	P	I	I
Nitrous Oxide (NOx)	X	X	X				X	I	I	P	I	I
Greenhouse Gases/Hydrocarbons	X	X	X				X	I	I	P	I	I
Temperature	I	I	I				I			I		
Barometric Pressure	I	I	I	I			I		P	I		

Data Element	Technology											
	Vehicle Data Sources		Connected Vehicle Technologies			PEMS	Fleets	Infrastructure-based Technologies			Hybrid Approaches	
	CAN Bus	OBD II	Retrofit and Integrated Devices	After-Market Safety Device	Here I Am	PEMS	Fleet-Based Systems	Remote Sensing Devices (RSDs)	Air Quality Monitoring Stations	Environmental Sensor Stations	Hybrid Approach – PEMS and RSDs	Hybrid Approach – Connected Vehicles and RSDs
Relative Humidity									P	I		
Precipitation										I		
Pavement Temperature										I		
Wind										I		
Average Vehicle Speed	I	I	I	I	M		P	P			P	P
Instantaneous Vehicle Speed	I	M	I	M	M							
Acceleration/ Deceleration Rates	I	M	I	M	M							
Braking	I	M	I	M	M							
Engine Idling	I	M	I	M								
Engine Starts	I	I	I	M			I					
Tail-Pipe Emissions	M	M	M	M		I	M	I			I	I
Engine speed RPM (Rotations per minute)	I	I	I	I								
Fuel consumption	I	I	I	I			I					
Air / Fuel Ratio	I	I	I	I								
Intake Temperature	I	I	I	I								
Battery Voltage	I	I	I	I								
Vehicle Mileage	I	I	I	I								
Vehicle Fuel Type	P	P	P	P								
Time Spent Idling	M	M	M	M	M							
Idling Location			M	M	M							

Key: X=Indicator light is switched on if emissions eXceeds 1.5 the standard level for the vehicle model year; I = Included; P = Possibly Included; M = may be able to be modeled based on data provided by this source.

6.3 Recommendations for More Advanced Data Acquisition Technologies

In this section, general recommendations related to data acquisition technologies and collecting environmental data are provided. As specified in the SOW, recommendations related to collecting additional data and recommendations related to more data acquisition technologies to capture data at different levels of granularity are also provided.

- First, **more deployment of sensors and data acquisition technologies** may be the way to capture more environmental data that is useful to the program, for the AERIS transformative applications, and in the models described in the other State-of-the-practice reports. As Tables 3 and 4 show, the different technologies vary with respect to costs and ease of acquiring environmental data. Different data acquisition systems provide different data. Different applications and models may require different kinds of data. Individual vehicle data may be useful to a degree (especially for capturing gross polluters) but many environmental applications and environmental models will likely use aggregated data. Thus the emissions measured by an ESS may be ideal, but they likely only apply to the area close to the ESS. So it is likely that a full deployment of environmental data acquisition systems will include connected vehicle data that utilizes OBD II information, a way to capture and aggregate the connected vehicle data conveying a broader geographical area, and remote sensing devices and ESS that capture individual and area-wide data at specific points. The AERIS program must determine what data and how much data are needed to support the interests of the AERIS program. This analysis may lead to selective deployment of sensors and data acquisition technologies based on the needs of the program.

- **More research into hybrid approaches** that use the data from a subset of vehicles captured either with PEMS or connected vehicle devices but that cover a larger spatial area with data from all vehicles that pass a specific point monitored by a remote sensing device system is recommended. Properly weighting such data should provide area-wide aggregate estimates that include all vehicles (not just equipped vehicles) over a larger area than just a point. By fusing the data from multiple sources, the real-time emissions variances that are related to temperature changes, roadway terrain, and barometric pressure can be captured. It is likely that this enhanced data will be more appropriate for triggering and monitoring the transformative AERIS applications.

- An additional general data recommendation is to **leverage data from and technology developed for the Michigan Test Bed and Safety Pilot Projects**. As described in this report, there are also **potential data sets and methodologies developed in the BAA research projects** (such as the Calmar and UC Riverside data and methodologies described earlier) **that can be leveraged**.

6.3.1 More Data Acquisition Technologies to Collect Additional Data

This report has identified that there are many ESS stations that do not include air quality monitors. Adding air quality sensors to this existing infrastructure and using the communications method that the ESS uses for conveying its road weather data is likely a cost-effective way to get aggregated point-based static environmental data.

Instead of investing in more remote sensing device systems, it may be more cost-effective to capture individual vehicle emissions data using connected vehicle equipment; however, like all connected vehicle data, waiting for penetration of connected vehicle devices may be difficult. And there is likely a correlation between gross polluters and slow adopters of connected vehicle equipment. Thus, in order to collect environmental data from all passing vehicles, a remote sensing device using an infrared beam to capture emissions is necessary. Such data acquisition systems are likely environmental applications themselves in that they can capture gross polluters and have a generally high impact on reducing emissions by requiring that gross polluters fix their vehicles.

6.3.2 More Data Acquisition Technologies to Capture Data at Different Levels of Granularity

Capturing data at different levels of granularity is not straight-forward in that some data acquisition technologies capture data aggregates and some capture individual data. In general, a greater number of deployed data acquisition technologies and more equipped vehicles will result in greater granularity of available data.

6.4 Recommended Technologies and Approaches for Collecting Data for the MOVES Emissions Model

Calibrating the MOVES emission model or using it to model real-time impacts of transformative AERIS applications will likely require collecting emissions data from as many vehicles as possible over as many roadway links as possible. It is not clear that using only connected vehicle data to calibrate MOVES or model real-time impacts is the best approach because it's likely that vehicles with connected vehicle devices will be relatively new and relatively well-maintained compared to the general vehicle fleet. Thus a hybrid approach such as described in Section 5.0 and Section 6.3 in order to capture data covering a wide space from a smaller number of equipped vehicles and all vehicles passing a specific point/RSD is recommended.

7.0 REFERENCES

This section presents the list of reports and references used to conduct the state of practice scan of data acquisition technologies.

ARCADIS G&M, Inc. *Evaluation of Fugitive Emissions Using Ground-Based Optical Remote Sensing Technology,* 2007, found at: http://www.epa.gov/nrmrl/pubs/600r07032/600r07032.pdf (accessed Jun 20, 2011).

Bishop et al., *On-Road Motor Vehicle Emissions Including Ammonia, Sulfur Dioxide, and Nitrogen Dioxide*, found at: http://www.arb.ca.gov/research/seminars/bishop/bishop.pdf (accessed May 16, 2011).

EPA, Clean Air Research Science Products, found at: http://www.epa.gov/airscience/products.htm (accessed May 16, 2011).

EPA Technology Transfer Network Emission Measurement Center, found at: http://www.epa.gov/ttn/emc/prelim.html (accessed May 16, 2011).

European Commission Joint Research Center Institute for Environment and Sustainability. (2010). *In-Use Emissions Testing and Portable Emissions Measurement Systems (PEMS).* http://ies.jrc.ec.europa.eu/eu-pems (accessed May 2, 2011).

FHWA Road Weather Management Program, "Interactive Environmental Sensor Station," found at: http://www.ops.fhwa.dot.gov/weather/mitigating_impacts/interactive_ess.htm (accessed May 16, 2011).

Gibbons, Eric "Urban NTCIP Road Sensor Station Applications," found at: http://www.highsierraelectronics.com/misc_PDF/RoadSensorStationPaper.pdf (accessed May 16, 2011).

Glassco, Richard, et al. *State-of-the-practice of Techniques for Evaluating the Environmental Impacts of ITS Deployment,* December 2010.

Griffin Technology. (2011). *CarTrip OBD-II Hardware Interface.* http://www.griffintechnology.com/products/cartrip?sms_ss=facebook&at_xt=4d9109f13084c945,0# (accessed May 2, 2011).

Koupal, John, "Portable Emission Measurement—U.S. EPA Perspective" presented at the PEMS Conference March 24, 2011, found at: http://www.cert.ucr.edu/events/pems2011/01_John%20Koupal.pdf (accessed May 16, 2011).

National Motorists Association, "How Remote Sensing Works," found at http://www.motorists.org/emissions/remote-sensing (accessed May 16, 2011).

NTCIP ITS Standard 1204, November 2009, pages 44-45.

RITA ITS Costs Database, "Detailed costs of road weather information systems deployed at several sites north of Spokane, WA," found at: http://www.itscosts.its.dot.gov/its/benecost.nsf/ID/D9FDC51609AAD49085256EC90059ED7E?OpenDocument&Query=CApp (accessed May 16, 2011).

RITA ITS Cost Database entry, "Maryland State Highway Administration estimated fog warning system addition to existing environmental sensor stations near Big Savage Mountain, Maryland cost $75,000," found at: http://www.itscosts.its.dot.gov/its/benecost.nsf/ID/D7E73D3356D8CD0185256FD4004A1104?OpenDocument&Query=CApp (accessed May 16, 2011).

RITA ITS Deployment Statistics Database, "ESS Deployment," found at: http://www.itsdeployment.its.dot.gov/ResultsStateNational.asp?ID=1152&year=2004 (accessed May 16, 2011).

Sensors, Inc. (2011). *SEMTECH Product Line of Portable Emissions Measurement Systems (PEMS).* http://www.sensors-inc.com/onboard.html (accessed May 2, 2011).

Smogtips.com, "AB 2289—New Smog Check Law," found at http://www.smogtips.com/new-smog-law-AB-2289.cfm (accessed May 16, 2011).

Smogtips.com, "Roadside Emissions and Remote Smog Test Checkpoints," found at http://www.smogtips.com/remote_sensing.cfm (accessed May 16, 2011).

U.S. Environmental Protection Agency, Office of Transportation and Air Quality. (2005). *Assessment and Standards Division In-Use Testing Program for Heavy-Duty Diesel Engines and Vehicles.* http://epa.gov/otaq/regs/hd-hwy/inuse/420r05006.pdf (accessed May 2, 2011).

University of California at Riverside-Center for Environmental Research & Technology. (2011). CMEM-Model. http://www.cert.ucr.edu/cmem/model.html (accessed May 2, 2011).University of California Riverside-, Center for Environmental Research and Technology, and Calmar Telematics LLC. (2011). *Research on Intelligent Transportation System Application to Improve Environmental Performance, DRAFT TASK 1 REPORT,* 2011.

University of California Riverside-, Center for Environmental Research and Technology, and Calmar Telematics LLC. (2011). *Research on Intelligent Transportation System Application to Improve Environmental Performance, DRAFT TASK 2 REPORT, 2011.*

Email communication with Rob Wilson of Sensors, Inc. on May 2, 2011.

XATA Turnpike, Inc. (2011). RouteTracker Product Overview, found at http://eobr.com/product_overview/index.php. (Accessed May 2, 2011).

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487
www.its.dot.gov

FHWA-JPO-11-134

U.S. Department of Transportation
Research and Innovative Technology Administration