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16. Abstract

Identifying applications that can reduce fuel consumption and emissions from surface transportation is an important strategy in solving transportation's environmental dilemma. The U.S. Department of Transportation (U.S. DOT) has set out to investigate the problem through several initiatives, one of which is connected vehicle research. The purpose of this report is to document the state of the practice for applications that have demonstrated environmental benefits through ITS technologies, or have the potential to do so, and identify opportunities to leverage existing research. The findings outlined in the report will assist the U.S. DOT in planning and implementing the Applications for the Environment: Real-Time Information Synthesis (AERIS) Program. The findings will also provide the basis for identifying opportunities to further examine and research applications for improving environmental decisions by public agencies and consumers and for improving environmental outcomes through ITS.

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Executive Summary

In the United States (U.S.) alone, more than 250 million registered motor vehicles consume 168 billion gallons of fuel to travel almost 3 trillion miles on U.S. roads per year.[1] These activities do not occur without impacts on the nation's environment. In fact, surface transportation activities are responsible for almost one quarter of all greenhouse gas (GHG) emissions in the United States.[2] Transportation is also the "fastest-growing source of U.S. greenhouse gas emissions, accounting for 47 percent of the net increase in total U.S. emissions since 1990, and is the largest end-use source of CO_2, which is the most prevalent greenhouse gas."[3] These statistics do not include life cycle emissions for the transportation sector, which includes the emissions of a product from extraction of raw materials through disposal, or "cradle to grave" emissions, which can also be significant.[4]

Identifying applications that can reduce fuel consumption and emissions from surface transportation is an important strategy in solving transportation's environmental dilemma. The U.S. Department of Transportation (U.S. DOT) has set out to investigate the problem through several initiatives, one of which is connected vehicle research. Connected vehicle research is a multimodal initiative that aims to enable safe, interoperable networked wireless communications among vehicles (light vehicles, transit, and freight), the infrastructure, and passengers' personal communication devices. As part of the connected vehicle research effort, the U.S. DOT Intelligent Transportation Systems (ITS) Joint Program Office (JPO) initiated the Applications for the Environment: Real-Time Information Synthesis (AERIS) research program to generate and/or acquire environmentally relevant real-time transportation data to create actionable information to support and facilitate "green" transportation choices by transportation system users and operators. The AERIS program will better define how connected vehicle data and applications might contribute to mitigating some of the negative environmental impacts of surface transportation.

The purpose of this report is to document the state of the practice for applications that have demonstrated environmental benefits through ITS technologies, or have the potential to do so, and identify opportunities to leverage existing research. The findings outlined in the report will assist the U.S. DOT in planning and implementing the AERIS Program. The findings will also provide the basis for identifying opportunities to further examine and research applications for improving environmental decisions by public agencies and consumers and for improving environmental outcomes through ITS.

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[1] U.S. Department of Transportation. (2009), *Table 4-9: Motor Vehicle Fuel Consumption and Travel*. Retrieved August 9, 2011, from http://www.bts.gov/publications/national_transportation_statistics/html/table_04_09.html
[2] U.S. Environmental Protection Agency. (2008). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006* . Retrieved January 7, 2011, from http://www.epa.gov/climatechange/emissions/downloads/08_CR.pdf
[3] U.S. Environmental Protection Agency. (2010). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008* . Retrieved January 7, 2011, from http://www.epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010_Chapter2-Trends.pdf
[4] U.S. Department of Transportation. (2010). *Transportation's Role in Climate Change*. Retrieved January 7, 2011, from Transportation and Climate Change Clearinghouse: http://climate.dot.gov/about/transportations-role/overview.html

To create this report, a broad scan of published literature was conducted on existing initiatives and research on ITS and the environment within the U.S. DOT, other public agencies, the private sector, and academia. The focus of the scan was the connected vehicle environment (i.e., vehicle data communicated to the infrastructure that can be processed to create actionable information supporting "green" choices). The scan included passenger vehicles, freight vehicles, and transit vehicles, and encompasses both domestic and international activities. The scope of environmental benefits documented in this report is limited to reductions in GHG emissions, criteria air pollutants, and fuel consumption. The scan did not cover environmental data acquisition technologies, environmental models, activity-based models, or evaluation techniques. Additional U.S. DOT state of the practice reports address these topics, creating a comprehensive baseline of knowledge.

The findings from this report are organized into seven application categories:

1. *Demand and Access Management Applications:* Applications that aim to reduce travel demand by controlling access to roadways, improving pedestrian and transit options, and encouraging policies that reduce demand at peak hours.

2. *Eco-Driving Applications:* Applications that target individual drivers with the objective of promoting a driving style that lowers vehicle emissions.

3. *Logistics and Fleet Management Applications:* Applications that reduce emissions through services that optimize vehicle maintenance, telematics, and driver, speed, and fuel management.

4. *Traffic Management and Control Applications:* Applications that provide the ability to analyze current traffic conditions and dynamically adjust to accommodate different types of traffic or changing conditions.

5. *Freight Applications:* Applications that reduce freight emissions through the exchange of information that allows for more efficient management of freight travel and delivery.

6. *Transit Applications:* Applications that reduce transit emissions through the exchange of information that allows for optimization of transit travel and mode shift.

7. *Other Applications:* Other applications of interest with the potential to create environmental benefits through ITS applications.

In general, it was found that limited research has been conducted regarding the environmental benefits of ITS applications, though there is a growing body of research focused on the issue. Of the research that has been completed, it was found that most individual ITS applications have fairly limited environmental benefits on their own. Some of the more significant environmental benefits found in the state of the practice assessment include:

- *Demand and Access Management Applications:* Congestion pricing strategies employed internationally have shown the ability to reduce particulate matter (PM) up to 20 percent, reduce carbon dioxide (CO_2) emissions up to 14 percent, reduce nitrogen oxides (NO_x) up to 15 percent, and reduce the number of days that exceed air quality standards.
- *Eco-Driving Applications:* Navigation systems with eco-routing features have assisted drivers in improving fuel economy up to 15 percent.

- *Logistics and Fleet Management Applications:* Idle-off stop-start systems can reduce emissions up to 20 percent in urban environments, and idle reduction technologies for freight rest stops have demonstrated the ability to reduce emissions by 83 percent.
- *Traffic Management and Control Applications:* Traffic signal coordination and optimization can reduce emissions up to 22 percent and has a 40:1 return on investment.
- *Freight Applications:* Platooning freight vehicles has the potential to reduce fuel consumption by 10 to 20 percent.
- *Transit Applications:* Transit Signal Priority (TSP) studies conducted in England reported that bus emissions were reduced up to 30 percent, but non-transit vehicle emissions increased up to 11 percent.

Tradeoffs were also observed in the literature, often when select vehicles were given mobility priority over other vehicles. For example of a tradeoff was found in a study on adaptive signal control, an application that coordinates control of traffic signals across a signal network, adjusting the lengths of signal phases based on prevailing traffic conditions. In one instance, adaptive signal control reduced emissions up to 50 percent for travel in the direction favored by the signal, but travel in the direction that is not favored by the signal had emissions increase up to 9 percent. These examples highlight that while some applications can decrease emissions for select vehicles, there is the potential that the mobility and emissions of other vehicles can be negatively impacted. Additional research is needed to analyze the net benefits in such situations.

Comparing the environmental benefits across the application categories is not a seamless process. Data documenting the environmental benefits of ITS applications are relatively limited and are presented in various metrics. Some benefits are documented in percentage reductions in emissions, fuel, or vehicle miles traveled (VMT) as compared to a baseline. GHG emissions and air pollutant reductions are reported using a number of metrics, including metric tons of CO2 equivalent (MTCE), CO2 equivalencies (CO2e), grams, and grams per kilowatt-hour (g/kWh). A common metric is needed to accurately compare applications in terms of environmental benefits.

Additional research will need to be performed to determine what environmentally relevant data is available from cars, trucks, buses, and other vehicle modes. Once a baseline of available data is determined, it will be necessary to assess what types of data can be used to make improvements in current models and algorithms. Providing relevant data to drivers is also a key factor in reducing surface transportation emissions. It is important to determine the best in-vehicle data to integrate with the transportation system and how to use that data to incentivize drivers to make greener transportation choices or facilitate network-wide “green” decision-making.

In terms of performance, it will be necessary to define the minimum environmental benefits that are acceptable for an individual application and/or a portfolio of applications, and by geographic scale (i.e. national, local, or corridor). Performance measures will help the AERIS Program to determine the applications that are viable for the future, candidates for more in-depth testing, and selection of applications for modeling and possibly deployment.

1.0 Introduction

Connected vehicle research is both a concept and a program of services that can transform travel as we know it. Connected vehicle research combines leading edge technologies – advanced wireless communications, on-board computer processing, advanced vehicle-sensors, Global Positioning System (GPS) navigation, smart infrastructure, and others – to provide the capability for vehicles to identify threats, hazards, and delays on the roadway and to communicate this information over wireless networks to provide drivers with alerts, warnings, and real time road network information. At its foundation is a communications network that supports vehicle-to-vehicle (V2V) two-way communications, vehicle-to-infrastructure (V2I) one- and two-way communications, and vehicle or infrastructure-to-device (X2D) one- and two-way communications to support cooperative system capability. Connected vehicles enable a surface transportation system in which vehicles do not crash and roadway operators and travelers have the information they need about travel conditions to operate more effectively. Connected vehicle research will establish an information backbone for the surface transportation system that will support applications to enhance safety and mobility and, ultimately, enable a crashless, information-rich surface transportation system. Connected vehicle research also support applications to enhance livable communities, environmental stewardship, and traveler convenience and choices.

The ability to identify, collect, process, exchange, and transmit real-time data provides drivers with an opportunity for greater situational awareness of the events, potential threats, and imminent hazards within the vehicle's environment. When combined with technologies that intuitively and clearly present alerts, advice, and warnings, drivers can make better and safer decisions while driving. Additionally, when further combined with automated vehicle-safety applications, connected vehicle technology provides the vehicle with the ability to respond and react in a timely fashion when the driver either cannot or does not react quickly enough. Vehicle safety systems, because of the need for frequently broadcasted, real-time data, are expected to use dedicated short range communications (DSRC) technology, for active safety applications. Many of the other envisioned applications could use other technologies, such as third generation (3G) cellular or other Wireless Fidelity (Wi-Fi) communications, as well as DSRC. The rapid pace of technological evolution provides tremendous opportunities for connected vehicles, and the program is positioned to capitalize upon these advances as they happen.

As part of the connected vehicle research effort, the United States Department of Transportation (U.S. DOT) Intelligent Transportation Systems (ITS) Joint Program Office (JPO) initiated the Applications for the Environment: Real-Time Information Synthesis (AERIS) research program to generate and/or acquire environmentally relevant real-time transportation data to create actionable information to support and facilitate "green" transportation choices by transportation system users and operators. The AERIS program will better define how connected vehicle data and applications might contribute to mitigating some of the negative environmental impacts of surface transportation by:

- Supporting research into the generation, capture, standardization, and use of real-time data present in the transportation system (i.e., connected travelers, vehicles and infrastructure) to enable environmentally beneficial choices by system users and system operators.

- Leveraging existing research and stakeholder activities to create a unique body of knowledge and experience that demonstrates the most effective uses of ITS to reduce the negative impacts of transportation on the environment.
- Forming the foundation for addressing future, long-range efforts to conserve energy, address air quality issues, mitigate other environmental impacts of the transportation system, and support likely environmental goals in the new transportation authorization.

The AERIS Program is delineated into three phases, extending over five years: Foundational Analysis (Phase I); Candidate Applications Evaluation (Phase II); and Research Investment Planning (Phase III). Each phase has six major tracks that span across the entire duration of the AERIS program:

1. *Establish Foundation:* In this track, foundational research will be conducted to identify ITS applications/strategies that have been implemented to improve environmental decisions by public agencies and consumers, and environmental outcomes. Additionally, data that will facilitate the development of research to support "green choices" will be identified. An evaluation framework will be also developed to compare promising applications/strategies.

2. *Identify Candidate Strategies:* In this track, the ITS applications/strategies that can *effectively* reduce/mitigate the negative environmental impacts of transportation will be identified. Transformative concepts, integrated operational concepts that illustrate how vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data and communications can be used in innovative ways to operate surface transportation networks to reduce environmental impacts resulting from transportation-related emissions and fuel consumption, will be developed. A high-level benefit-cost analysis will be conducted to down-select the candidate applications/strategies for further evaluation.

3. *Analyze and Evaluate Candidate Strategies:* In this track, the candidate applications/strategies will be evaluated using the framework developed in track 1 to identify the most promising applications/strategies for further research or real-world demonstrations.

4. *Recommend Strategies and Applications:* Under this track, recommendations will be developed for further Federal investment in the most effective applications/strategies either for additional research or for real-world demonstrations.

5. *Policy and Regulatory Research:* Under this track, policy, regulatory, and knowledge transfer issues and needs will be explored and possibly resolved.

6. *Stakeholder Interactions and Technology Transfer:* This track deals with the effective engagement of the stakeholder community and experts in the field to participate as well as provide feedback on the AERIS research path.

The research for and the delivery of this AERIS Applications State of the Practice Assessment Report is an activity that falls under Track 1 of Phase I.

1.1 Purpose

This report was prepared to contribute to a baseline body of knowledge about ITS and the environment. The purpose of this report is to document the state of the practice for applications that have demonstrated environmental benefits through ITS technologies, or have the potential to do so, and identify opportunities to leverage existing research. Findings documented here will assist the U.S. DOT in planning and implementing the AERIS Program, and they will also provide the basis for identifying opportunities to further examine and research applications for improving environmental decisions by public agencies and consumers and for improving environmental outcomes through ITS.

1.2 Scope

To create this report, a broad scan of published literature was conducted on existing initiatives and research on ITS and the environment within the U.S. DOT, other public agencies, the private sector, and academia. Proceedings from transportation-focused conferences were reviewed and searched for key environmental terminology, such as emissions, pollutants, greenhouse gases[5] (GHGs), air quality, or eco, environment, and sustainability. While a wide scope of literature was reviewed, it is important to note that there may be existing research activities and applications that were not found in the literature that was reviewed. This report is expected to be a living document, and further input on applications that demonstrate environmental benefits, as well as documented results, is welcome.

The focus of the scan was the connected vehicle environment (i.e., vehicle data communicated to the infrastructure that can be processed to create actionable information supporting “green” choices). The scan included passenger vehicles, freight vehicles, and transit vehicles, and encompasses both domestic and international activities. The scan did not cover environmental data acquisition technologies, environmental models, activity-based models, or evaluation techniques. These topics will be covered in additional state of the practice reports to create a comprehensive baseline of knowledge.

[5] GHGs include: Carbon Dioxide (CO_2); Methane (CH_4); Nitrous Oxide (N_2O); and Fluorinated Gases, including Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

2.0 Transportation and the Environment

Transportation activities accounted for 28 percent of all GHG emissions in the United States in 2006, and on-road vehicles contributed 78 percent to that total. This means that surface transportation is responsible for 23 percent of all GHG emissions in the United States.[6] Transportation is also the "fastest-growing source of U.S. greenhouse gas emissions, accounting for 47 percent of the net increase in total U.S. emissions since 1990, and is the largest end-use source of CO2, which is the most prevalent greenhouse gas."[7] Nearly "97 percent of transportation GHG emissions came through direct combustion of fossil fuels." These statistics do not include life cycle emissions for the transportation sector, which includes the emissions of a product from extraction of raw materials through disposal, or "cradle to grave" emissions, which can also be significant.[8] Therefore, finding applications that can reduce emissions from surface transportation is an important strategy in addressing climate change.

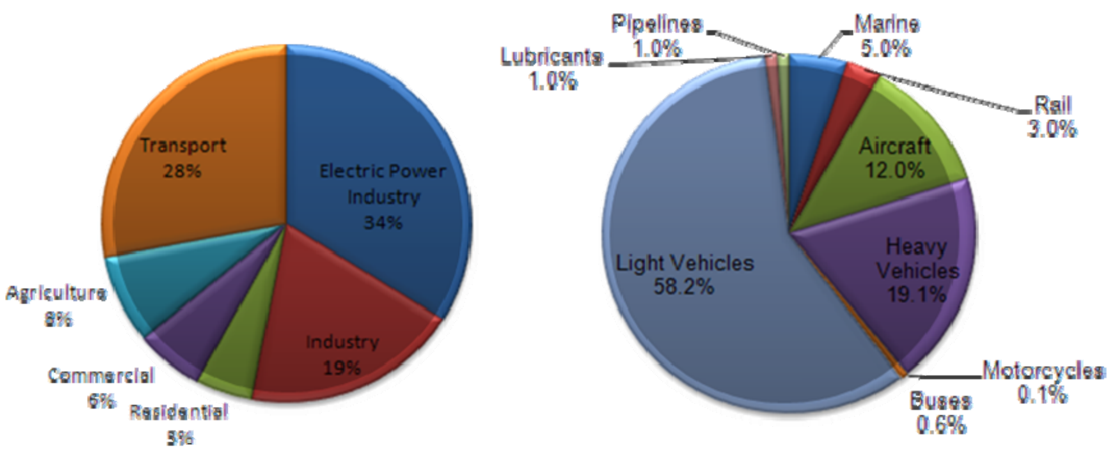

Figure 2-1. Surface Transportation's Impact on the Environment

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[6] U.S. Environmental Protection Agency. (2008). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006* . Retrieved January 7, 2011, from http://www.epa.gov/climatechange/emissions/downloads/08_CR.pdf

[7] U.S. Environmental Protection Agency. (2010). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008* . Retrieved January 7, 2011, from http://www.epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010_Chapter2-Trends.pdf

[8] U.S. Department of Transportation. (2010). *Transportation's Role in Climate Change*. Retrieved January 7, 2011, from Transportation and Climate Change Clearinghouse: http://climate.dot.gov/about/transportations-role/overview.html

In a recent United States Environmental Protection Agency report, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, several explanations for the increase in emissions from transportation sources are discussed. First, light-duty vehicle miles traveled (VMT) increased by 37 percent, in part because of “population growth, economic growth, urban sprawl, and low fuel prices” that occurred between 1990 and 2008. Second, while the total average fuel economy of vehicles increased during this time, the average fuel economy of vehicles sold during this time decreased. This trend occurred because of the growing popularity of light duty trucks, including sport utility vehicles, which accounted for more than half of the vehicle market in 2004. Finally, nearly all vehicles use and burn petroleum-based fuels “with more than half being related to gasoline consumption in automobiles and other highway vehicles.” As VMT and sales of vehicles with poor fuel economy increased, petroleum consumption also increased, which led to an increase in emissions.[9]

Connected vehicle applications can assist in reducing VMT, vehicle efficiency, and petroleum consumption, which can potentially reduce emissions. For purposes of the AERIS Program, applications are technological solutions (e.g., software, hardware, interfaces) designed to ingest, process, and disseminate data in order to address a specific strategy. Applications may be complemented with regulatory and educational tools. The remainder of the report describes connected vehicle applications, or applications that have the potential to use ITS, that can reduce emissions and benefit the environment. Some connected vehicle applications or strategies, where strategies are defined as operational activities that aim to achieve a specific goal, are incremental improvements to traditional approaches, and others are more transformational. Both types are enabled by V2V and V2I communications.

[9] U.S. Environmental Protection Agency. (2010). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008* . Retrieved January 7, 2011, from http://www.epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010_Chapter2-Trends.pdf

3.0 Application Assessments

This report discusses applications based on categories from the following reports:

- Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions, European Commission-Japan Ministry of Trade and Industry (EC-METI) Task Force, March 2009
- Impact of Information and Communication Technologies on Energy Efficiency in Road Transport, European Commission, September 2009

After reviewing the above reports as well as over 300 sources of published literature, seven categories were established for this state of the practice report. The categories were developed based upon natural breaks that were found in the literature review. The categories found in this report are as follows:

- Demand and Access Management Applications
- Eco-Driving Applications
- Logistics and Fleet Management Applications
- Traffic Management and Control Applications
- Freight Applications
- Transit Applications
- Other Applications

Alternative fuels and alternative fuel vehicles (AFVs) are discussed in Appendix C. While current applications of alternative fuels and AFVs do not necessarily involve the use of ITS technologies, there is potential for integrating their use with transformative ITS applications. Alternative fuels and AFVs may also offer additional emissions reductions when combined with other applications.

3.1 Demand and Access Management Applications

Demand and access management applications aim to reduce travel demand through strategies and policies "to control access to highways, major arterials, and other roadways. The benefits of access management include improved movement of traffic, reduced crashes, and fewer vehicle conflicts."[10] Demand and access management applications can offer cost-effective strategies that help to increase freeway capacities without investing in a new, or expanding upon the existing, infrastructure.

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[10] U.S. Department of Transportation. (2008). *Access Management*. Retrieved January 07, 2011, from Federal Highway Administration: http://www.ops.fhwa.dot.gov/access_mgmt/index.htm

Demand and access management includes a broad range of strategies—from including or improving pedestrian-oriented design elements, to including and improving public transportation infrastructure, to encouraging flex-time work schedules to reduce congestion at peak times. Improved transportation system operations that use ITS strategies are another critical aspect of demand and access management. In fact, "some transportation experts believe TDP [Time, Distance, and Place] pricing is an integral part of the next generation in transportation demand management."[11]

Applications in this category include congestion pricing and mileage based fees.[12] Electronic toll collection (ETC) systems have played an instrumental role in these applications and are also discussed in this category. The literature review found that demand and access management applications do have the potential to deliver some environmental benefits. Policies that increase the cost of driving can lead drivers to seek alternative modes of transportation. Cordon, congestion, and parking pricing policies generally show a two to three percent reduction in VMT. Pricing and fuel taxes show an 8 to 16 percent reduction in VMT. However, for the greatest VMT reductions, the literature generally shows that a region should combine land-use policies, pricing strategies, and transit investments.[13]

3.1.1 Electronic Toll Collection (ETC)

The U.S. DOT defines electronic payment systems as a way to "employ various communication and electronic technologies to facilitate commerce between travelers and transportation agencies, typically for the purpose of paying tolls and transit fares. Pricing refers to charging motorists a fee or toll that varies with the level of demand or with the time of day."[14] One type of an electronic payment system is ETC. ETC aims to eliminate the delay at toll booths by collecting tolls electronically. When a vehicle passes electronic sensors near the tolling station, the system determines which vehicles are enrolled in the ETC program, notifies enforcement authorities of vehicles that passed through but are not enrolled, and electronically debits the accounts of registered vehicle owners without requiring them to stop. ETC systems save registered cars time by eliminating stops at a toll window or machine, allowing them to travel at a higher average speed. As a result, delay at the toll gate is reduced and throughput is increased. ETC systems also help to reduce excessive acceleration and breaking which reduces emissions, and these systems can promote ride sharing and transit through financial disincentives.

ETC systems involve a number of technologies, including:

- Toll plaza sub-systems, including electronic tool reader and high-speed camera.
- Toll administration sub-systems, including hardware and software.

[11] Replogle, M. (2008, September). *Next Generation Travel Demand Management: Time-Distance-Place Motor Vehicle Use Charges.* Retrieved December 28, 2010, from Institute for Transportation and Development Policy: http://www.itdp.org/documents/Next%20Generation%20Travel%20Demand%20Management.pdf
[12] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.
[13] Bedsworth, L. W. (2010). *Climate Change Challenges: Vehicle Emissions and Public Health in California.* San Francisco: Public Policy Institute of California.
[14] U.S. Department of Transportation. (n.d.). *Application Area Definitions*. Retrieved December 28, 2010, from ITS Benefits Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ByInfo/WhatIsAppAreas

- Roadside telecommunications, including conduit design and installation and fiber optic cable installation.[15]

Figure 3-1. Electronic Toll Collection[16]

A telecommunications technology frequently used in the implementation of ETC systems is Dedicated Short Range Communication (DSRC). DSRC "is the most common form of primary electronic congestion-pricing technology in general use and is the standard on most free-flow toll facilities. The technology is based on on-board units (OBUs), sometimes referred to as tags or transponders, which communicate with gantry-mounted equipment at checkpoints. The roadside equipment identifies and verifies each vehicle's OBU, and depending on the type of system, either processes a charge from its designated account or confirms its rights of access."[17]

The U.S. has a wide range of DSRC systems in place or in development. DSRC is used on the Dallas North Toll Road and on New York City and San Francisco bridges and tunnels. Most DSRC systems "are based on microwave communication," though some use infrared communications. The most common systems currently in use are based on a 5.8-GHz frequency, using the European Committee for Standardization (in French, Comité Européen de

[15] U.S. Department of Transportation. (2009). *Electronic Payment and Pricing*. Retrieved December 28, 2010, from ITS Costs Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/CostTerminators/EPS%20Toll%20Collection
[16] U.S. Department of Transportation. (2006). *Congestion Pricing – A Primer*. Retrieved August 11, 2011, from: http://www.ops.fhwa.dot.gov/publications/congestionpricing/congestionpricing.pdf
[17] U.S. Department of Transportation. (2009, May 5). *Technologies That Enable Congestion Pricing—A Primer*. Retrieved December 29, 2010, from Federal Highway Administration: http://ops.fhwa.dot.gov/publications/fhwahop08042/cp_prim2_04.htm

Normalisation (CEN)) CEN-278 standard. This "standard is now well developed and delivers robust and secure OBU devices with an average battery life of around 5 years." [18]

In 1999, the U.S. Federal Communications Commission allocated a portion of the 5.9 GHz band for the use of ITS. The "next generation of 5.9-GHz systems, which are being developed mainly in the United States to address a wider spectrum of intelligent transportation systems (ITS) and connected vehicle applications, will provide longer range communication and multiple channels. Although not currently in use on any operational pricing system, these OBUs are planned to become standard installations in all new vehicles within the next decade." [19]

ETC systems are currently in place in a number of locations in the United States and abroad. E-ZPass is one of the more predominant systems in the United States. It covers 14 northeastern and midwestern states, from Maine to Virginia, and stretching out to Illinois towards the west.[20] Registered E-ZPass customers are provided with an electronic transponder that attaches to the vehicle's front windshield and contains an electronic chip that holds information on the user's account. When passing through an E-ZPass toll facility, an antenna reads the transponder for the vehicle's account information, and the toll cost is deducted from the user's account.[21] The New Jersey Turnpike Authority and the Delaware River Port Authority, both of which use the E-ZPass system, offer reduced toll rates for vehicles that meet California's Super Ultra Low Emission Vehicle standard, which are 90 percent cleaner than the average new vehicle in the model year that it was manufactured.[22] It was estimated that E-ZPass saved 30 million gallons of fuel in 2007, in the states where E-ZPass operates, by eliminating queued, idling vehicles waiting to manually pay tolls. Approximately 265,000 metric tons carbon equivalent (MTCE) were eliminated as well. According to the EPA's GHG Equivalencies Calculator, this is equivalent to removing 50,669 passenger vehicles from roads annually.[23,24]

PrePass is another commercial vehicle ETC system in place in the United States. PrePass, in use at 288 sites in 29 states[25], is an automatic vehicle identification system that allows participating transponder-equipped commercial vehicles to bypass designated weigh stations, port-of-entry facilities, and agricultural interdiction facilities. Cleared vehicles may proceed at freeway speed, eliminating the need to stop. This increases efficiency for shippers and improves safety for all freeway users. In 2009, PrePass saved an estimated 21 million gallons of fuel for commercial vehicles, in the

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[18] U.S. Department of Transportation. (2009, May 5). *Technologies That Enable Congestion Pricing—A Primer*. Retrieved December 29, 2010, from Federal Highway Administration: http://ops.fhwa.dot.gov/publications/fhwahop08042/cp_prim2_04.htm

[19] Ibid.

[20] E-ZPass is accepted at toll locations in the follow states: Delaware, Illinois, Indiana, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Virginia, and West Virginia.

[21] E-ZPass. (2010). *Information: How It Works*. Retrieved January 3, 2011, from E-ZPass: http://www.ezpass.com/static/info/howit.shtml

[22] E-ZPass. (2010). *Information: Plan Descriptions and Discounts*. Retrieved January 3, 2011, from E-ZPass: http://www.ezpass.com/static/info/discount.shtml

[23] Birdsall, M. (March 2010 2010-March). Gas Fizzling: ITS are useful tools to weaken greenhouse-gas emissions. *Roads and Bridges* , pp. 32-34.

[24] The vehicle equivalency was calculated using the EPA's Greenhouse Gas Equivalencies Calculator, available online at http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results.

[25] Alabama, Arizona, Arkansas, California, Colorado, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Louisiana, Maryland, Michigan, Mississippi, Missouri, Montana, Nebraska, New Mexico, Ohio, Oklahoma, South Carolina, Tennessee, Utah, Virginia, West Virginia, Wisconsin, and Wyoming.

states where PrePass operates. This eliminated 46,873 MTCE. PrePass also reduced delays by more than 4.4 million hours and saved US commercial vehicles an estimated $460 million.[26]

Other examples where ETC systems have reduced emissions include:

- The Carquinez Bridge crosses the Carquinez Strait and connects Vallejo, California, with Crockett, California. An ETC system was deployed on the Bridge for several reasons, including reducing traffic congestion on the bridge and reducing air pollution and fuel consumption. The ETC resulted in an estimated time savings of 25,000 hours per year with a corresponding fuel savings of approximately 55,000 gallons per year and a reduction of 1.35 million grams of nitrogen oxide (NO_x).[27]
- A 2002 evaluation of the M-Tag ETC system (Maryland's EZ-Pass predecessor) at three major toll plazas outside Baltimore, Maryland, indicated these systems reduced environmentally harmful emissions by 16 to 63 percent. The analysis compared emissions prior to ETC deployment with those after ETC deployment. It showed a "40 to 63 percent reduction of hydrocarbon [HC] and carbon monoxide [CO], and approximately 16 percent reduction of nitrogen oxide in the study area."[28]
- A 2000 study of the New Jersey Turnpike's EZ-Pass system estimated 1.2 million gallons of fuel saved annually across 27 tolling locations with ETC. As a result, volatile organic compounds (VOCs) emissions were reduced by 0.35 tons per weekday with "80 percent of the reduction resulting from improved light-duty vehicle performance."[29]

3.1.2 Congestion Pricing

Congestion pricing, also known as "value pricing," works by "shifting purely discretionary rush hour highway travel to other transportation modes or to off-peak periods, taking advantage of the fact that the majority of rush hour drivers on a typical urban highway are not commuters." Removing as little as five percent of the vehicles from a congested roadway through pricing "enables the system to flow much more efficiently, allowing more cars to move through the same physical space." Variable charging strategies have been successful in other industries, including airline tickets, cellular phone rates, and electricity rates. There is a consensus among economists that "congestion pricing represents the single most viable and sustainable approach to reducing traffic congestion."[30]

There are four general types of congestion pricing strategies:

1. Variable priced lanes, including separated express toll and high-occupancy toll (HOT) lanes.

[26] PrePass. (2010, October). *About Us*. Retrieved December 28, 2010, from PrePass: http://www.prepass.com/aboutus/Pages/AboutUs.aspx
[27] Gillen, D., et al, *Assessing the Benefits and Costs of ITS Projects: Volume 2 An Application to Electronic Toll Collection California PATH program Research Report*, Report number UCB-ITS-PRR-99-10. March 1999.
[28] Saka, Anthony and Dennis Agboh, *Assessment of the Impact of Electronic Toll Collection on Mobile Emissions in the Baltimore Metropolitan Area,* Paper presented at the 81st Transportation Research Board Annual Meeting. Washington, District of Columbia. January 2002.
[29] Gillen, D., et al, *Operational and Traffic Benefits of E-ZPass to the New Jersey Turnpike,* Prepared by the Wilbur Smith Associates for the New Jersey Turnpike Authority. August 2001.
[30] US Department of Transportation Federal Highway Administration. (2008, October). *Congestion Pricing.* Retrieved December 13, 2010, from http://ops.fhwa.dot.gov/publications/fhwahop08039/fhwahop08039.pdf

2. Variable tolls on entire roadways, roadway segments, bridges or toll-free roads during rush hours.
3. Cordon (or zone-based) charging fees that charge drivers to enter and drive in congested areas.
4. Area-wide charges, including distance-based charging or mileage fees based on congestion levels.[31]

With congestion pricing, ETC systems can be used to keep traffic moving at freeway speeds. Vehicle transponders are used to electronically collect fees from drivers, which may be set depending upon the time of day or change dynamically to encourage efficient traffic flow. Other technologies can also be used to collect fees and tolls. For example, Germany uses global positioning system (GPS) units to collect autobahn fees. The GPS records charges based on the location of the vehicle, and the driver uploads this information and submits payments. GPS devices can also provide other services such as navigation and commercial fleet management services, and roadside equipment needs and other costs may be reduced.[32]

Cameras are "an essential complement to tags [transponders] and GPS units to gain a record of the identity of vehicles that do not have a working tag or GPS unit." Cameras visually record violators' license plates and automated license plate readers assist enforcement officials in quickly identifying violators' contact information. Based upon this information, a fine can be assessed.[33]

Other potential congestion pricing technologies are listed below.

- Roadside detection, control, and information.
- Transportation Management Center (TMC).
- Toll plaza and administration.
- Roadside telecommunications.[34]

Existing international congestion pricing projects have demonstrated environmental benefits.

3.1.2.1 London's Congestion Charge Zone

In 2003, London began operating a congestion charging zone covering eight square miles of Central London. The zone was expanded to portions of West London in 2007, nearly doubling in size. Drivers are assessed a daily fee of £8. However, in October 2010 Mayor Boris Johnson announced a number of changes to the zone. The western extension of the zone was removed after December 24, 2010, and the daily fee was increased to £10 on January 4, 2011.[35]

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[31] US Department of Transportation Federal Highway Administration. (2008, October). *Congestion Pricing.* Retrieved December 13, 2010, from http://ops.fhwa.dot.gov/publications/fhwahop08039/fhwahop08039.pdf
[32] Ibid.
[33] Ibid.
[34] Maccubbin, R. P., Staples, B. L., Kabir, F., Lowrance, C. F., Mercer, M. R., Philips, B. H., et al. (2008). *Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned: 2008 Update.* Washington, DC: US Department of Transportation.
[35] Transport for London. (2010). *Congestion Charging*. Retrieved December 14, 2010, from http://www.tfl.gov.uk/roadusers/congestioncharging/17094.asp

Road signs alert drivers when they are entering and leaving the charging zone, which operates Monday through Friday from 7:00am to 6:00pm, excluding holidays and the days between December 25th and January 1st. Upon entry, departure, and driving within the zone, cameras capture license plate numbers, and Automatic License Plate Recognition (ALPR) technology uses optical character recognition software to identify vehicles by their license plates and the software compares them to a database of Vehicle Registration Numbers (VRN) to analyze whether payment is required. Exemptions are given to a variety of vehicles, such as motorcycles, emergency vehicles, vehicles driven by or carrying disabled drivers, licensed taxis, and AFVs, and residents that live within the zone receive a 90 percent discount. Beginning January 4, 2011, vehicles that emitted 100g/km or less of CO_2 and met the Euro 5 standard for air quality were exempt from the fee, as well as plug-in hybrid electric vehicles.[36,37]

Eligible vehicles and drivers are assessed a daily charge of £10. There are a variety of ways to pay the charge. Drivers who enter the zone on a regular basis can pay in advance in monthly and annual increments at a discounted rate. Otherwise, drivers who are assessed the fee must pay in advance or by midnight on the day of travel. Late fees apply for payments received after this time. London accepts payments online, at select retailers, and by text message, phone, and mail (by mail requires payment 10 days in advance). In January 2011, an automated payment system was deployed allowing drivers to register with the payment system and have their debit or credit card charged on a monthly basis. Users of the automated payment system pay a reduced daily fee of £9.[38,39]

Emissions levels have decreased since implementation of the London Congestion Charging Zone. A study compared emission levels in 2002, when the zone did not exist, with levels in 2003. Both NO_x and Particulate Matter-10 (PM10)[40] were reduced by 13 and 15 percent, respectively. In addition to the environmental benefits, vehicle traffic declined by approximately 20 percent (around 20,000 vehicles per day) within Central London. This increased traffic speed by 37 percent during charging hours, from 8 miles per hour (mi/h) to 11 mi/h, and reduced taxi travel cost by 20 to 40 percent due to reduced delays. Impacts at the perimeter of the zone were neutral.[41]

[36] Transport for London. (2010, November). *What do I need to know about the central London Congestion Charging zone?* Retrieved December 14, 2010, from http://www.tfl.gov.uk/assets/downloads/congestion-charging.pdf

[37] Transport for London. (2010). *Congestion Charging*. Retrieved December 14, 2010, from http://www.tfl.gov.uk/roadusers/congestioncharging/17094.asp

[38] Transport for London. (2010, November). *What do I need to know about the central London Congestion Charging zone?* Retrieved December 14, 2010, from http://www.tfl.gov.uk/assets/downloads/congestion-charging.pdf

[39] Transport for London. (2010). *Congestion Charging*. Retrieved December 14, 2010, from http://www.tfl.gov.uk/roadusers/congestioncharging/17094.asp

[40] PM10 refers to particles less than 10 micrometers in diameter. PM10 is of concern because particles of this size can be inhaled.

[41] Litman, T. (2006, January 10). *London Congestion Pricing: Implications for Other Cities.* Retrieved December 14, 2010, from Victoria Transport Policy Institute: http://www.vtpi.org/london.pdf

3.1.2.2 London's Low Emission Zone

London also established a Low Emission Zone (LEZ) that began operating in February 2008 to address the city's poor air quality in order to improve the health and quality of life of city residents. London has the worst air pollution in the United Kingdom and is one of the more polluted cities in all of Europe. The LEZ "aims to reduce traffic pollution by deterring the most polluting diesel-engine lorries [trucks], buses, coaches, minibuses and large vans from driving within the city."[42]

The LEZ covers roadways 24 hours a day, seven days a week within the Greater London Authority boundary and currently applies to older diesel trucks, buses, and coaches, regardless of whether they are operated for commercial or private use or whether the vehicles are registered in the United Kingdom or another country. These vehicles must meet the Euro III standard for particulate matter (PM), or else pay a daily fee of £200 to drive in the LEZ. Euro III[43] standards limit emissions of CO to 2.1 grams per kilowatt hour (g/kWh), HC to 0.66 g/kWh, NO_x to 5.0 g/kWh, and PM to 0.10 g/kWh. Vehicles that also travel into the London Congestion Charging Zone must pay any applicable congestion fees. According to a 2006 study, concentrations of small particles from traffic sources were expected to decrease across London by 4.3 percent in 2008 and 8.0 percent in 2010 due to the LEZ, and NO_x is expected to decrease by 3.2 percent in 2008 and 4.1 percent in 2010.[44,45]

Road signs alert drivers when they are entering and leaving the charging zone. Similar to the Congestion Charging Zone, cameras capture license plate numbers, and ALPR technology uses optical character recognition software to identify vehicles by their license plates and the system software compares them to a database of vehicles that meet the LEZ emissions standards to analyze whether payment is required. Vehicles registered in other countries that meet the LEZ emissions standards and plan to travel in the LEZ must register with Transport for London in order to avoid fees. Exemptions are given to vehicles designed primarily for off-road use, classic vehicles built before 1973, military vehicles, and travelling salesperson vehicles.[46]

The LEZ does not apply to cars, motorcycles, and small vans. It was initially planned that diesel large vans and minibuses would also be included in the LEZ beginning in October 2010, but inclusion of these vehicles has been delayed to January 2012 due to economic conditions. At that time, these vehicles will be required to meet the Euro III standard for PM, or else pay a daily fee of £100 to drive in the LEZ. It is estimated that "including larger vans and minibuses in the LEZ in January 2012 would reduce emissions of Particulate Matter (PM) by around 80 tonnes [sic] and emissions of Oxides of Nitrogen (NO_X) by around 1,200 tonnes [sic] by 2015."[47,48]

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[42] Transport for London. (n.d.). *Low Emission Zone: Benefits*. Retrieved December 14, 2010, from http://www.tfl.gov.uk/roadusers/lez/about/2524.aspx
[43] Euro III is an emissions standard for heavy-duty diesel engines in Europe.
[44] Transport for London. (2010, September). *The Low Emission Zone is in operation.* Retrieved December 14, 2010, from http://www.tfl.gov.uk/assets/downloads/roadusers/lez/low-emission-zone-leaflet.pdf
[45] Bush, C. (2006, January). *Strategic Environmental Assessment of the Proposed Revisions to the Mayor's Transport Strategy and the Mayor's Air Quality Strategy to Introduce a Low Emission Zone.* Retrieved 14 December, 2010, from http://www.tfl.gov.uk/assets/downloads/roadusers/lez/LEZ/LEZ-strategy-revisions-environmental-report-summary-0601.pdf
[46] Transport for London. (2010, September). *The Low Emission Zone is in operation.* Retrieved December 14, 2010, from http://www.tfl.gov.uk/assets/downloads/roadusers/lez/low-emission-zone-leaflet.pdf
[47] Ibid.
[48] Transport for London. (2010). *Low Emission Zone: Consultation*. Retrieved September 14, 2010, from http://www.tfl.gov.uk/roadusers/lez/about/6573.aspx

3.1.2.3 Milan's Ecopass Program

On January 2, 2008, Milan, Italy, implemented Ecopass, a congestion charging program aimed at reducing air pollution from vehicle emissions. Ecopass applies a traffic pollution charge for some motorists traveling within a designated traffic restricted zone or ZTL (Italian: *Zone a Traffico Limitato*), corresponding to the central Cerchia dei Bastioni area, about 8.2 km^2.[49] The "program is based on a fee structure according to the vehicle's engine emission standards and funds raised through the charge are used to finance public transportation projects, cycle paths and green vehicles." This program is similar to the congestion pricing programs implemented in London, but employs variable pricing schemes.[50] Only vehicles with high-polluting engines entering the zone are charged, and those with older polluting engines are banned.[51] Vehicles that do not comply with the Euro3 and Euro4[52] emission standards are charged a fee for entering the defined congestion zone from 7:30 am to 7:30 pm. The amount of the fee varies from €2 to €10, with dirtier vehicles charged higher fees.[53]

A study comparing the types of vehicles and engines that entered the zone after implementation of the Ecopass program found that the number of older, dirtier vehicles entering the zone decreased dramatically. Vehicles subject to the charge fell by more than 56 percent, or approximately 21,274 vehicles per day, while vehicles exempt from the charge increased by more than 4 percent.[54] Additionally, a report by the Milanese Agency of Mobility and the Environment found that the first year of the Ecopass program reduced the number of days exceeding PM limits by 42 days, from 125 days prior to implementation of the zone to 83 days after the first year of implementation. The study also found that all traffic related emissions were reduced: PM10 was reduced by 23 percent; ammonium hydroxide (NH_3) was reduced by 47 percent; NO_x was reduced by 15 percent; and CO_2 emissions fell by 14 percent.[55]

3.1.2.4 Singapore's Area Licensing Scheme (ALS)

Singapore implemented the ALS Program, the world's first congestion pricing zone, in 1975. The initial process of creating and enforcing the zone was performed manually by law enforcement activities around the city center. Police would check vehicles to ensure that the paper license to enter the zone was displayed. The congestion charges were implemented as part of road pricing and vehicle ownership policies designed to protect Singapore's limited land, improve the economy, and reduce congestion.[56]

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[49] United Nations Environment Programme. (2010). *The European Union Automotive Fuel Economy Policy*. Retrieved January 3, 2011, from Global Fuel Economy Initiative: http://www.unep.org/transport/gfei/autotool/case_studies/europe/cs_eu_0.asp
[50] Ibid.
[51] Ibid.
[52] Euro3 and Euro4 are European emissions standards for passenger vehicles.
[53] Municipality of Milan. (2008, December). *Monitoraggio Indicatori Ecopass: Prime Valutazioni.* Retrieved December 28, 2010, from Comune di Milano: http://www.comune.milano.it/dseserver/ecopass/report/Monitoraggio_Ecopass_11Mesi.pdf
[54] Ibid.
[55] Ibid.
[56] K.T. Analytics, Inc. (2008, August). *Lessons Learned from International Experience in Congestion Pricing: Final Report.* Retrieved December 28, 2010, from U.S. DOT Federal Highway Administration: http://ops.fhwa.dot.gov/publications/fhwahop08047/intl_cplessons.pdf

Since its introduction, the ALS Program has gone through several alterations and expansions. In 1998, "the pricing program has been fully automated and charges are now collected electronically at more than 50 charge points spread across the city." Currently, the drivers that enter the zone between 7:00AM and 7:00PM (Monday through Friday) are charged rates that vary from zero to approximately $2 USD when crossing a charge point.[57] Research in Singapore estimated that the program saves 175,000 pounds of CO_2 emissions per day and has created more dispersed travel patterns.[58]

3.1.2.5 Stockholm's Congestion Tax

The Stockholm congestion tax was implemented as a tax placed on vehicles traveling into and out of the Stockholm, Sweden, city-center zone as a means to reduce traffic congestion and improve the environment. The congestion tax began as a seven-month trial program in 2006 and became permanent in August 2007. Vehicles that enter or exit the zone are required to pay 10 to 20 Swedish Krona ($1.49 to $2.98 USD) depending on the time of day.[59]

Vehicles that enter and exit the zone are identified through cameras, laser detectors, ALPR technology, and antennas that are mounted on gantries at each control point. Signs alerting drivers that they are entering and exiting the zone are also mounted on the gantries. The equipment identifies which vehicles have passed the control points, but does not automatically deduct the payment. Congestion tax bills are sent to vehicle owners at the end of each month.[60]

As with London and Singapore, "Stockholm also achieved environmental objectives as indicated by the observed reduction. Carbon Dioxide (CO_2) was reduced 10-14% in the inner city and 2-3% in the county. Stockholm also experienced a 7% reduction in NO_X and a 9% reduction in particulates." Additionally, the tax reduced the number of vehicles entering the zone by 100,000 per day. Revenue for Stockholm's congestion charging zone averages $60 million USD per year. The funds are used for new road construction in the Stockholm area.[61]

3.1.3 Mileage Based Fees

Mileage based fees, which are sometimes referred to as "pay-as-you-drive fees," involve on-board devices that charge fees based on infrastructure use to impact modal split and reduce VMT. The fees can include congestion pricing, higher fees for restricted zones, higher fees based on the time of the day, and other pricing schemes.[62] As regulators are looking to move away from fuel taxes, interest in mileage based fees is growing. Existing concerns over privacy, equity, and administrative costs will need to be addressed for implementation to move forward. Implementation from the technology viewpoint is relatively simple and involves deploying GPS-enabled mobile devices to track VMT, travel through pricing zones, and accrued fees. Mileage based fees have the potential to reduce GHG

[57] K.T. Analytics, Inc. (2008, August). *Lessons Learned from International Experience in Congestion Pricing: Final Report.* Retrieved December 28, 2010, from U.S. DOT Federal Highway Administration: http://ops.fhwa.dot.gov/publications/fhwahop08047/intl_cplessons.pdf
[58] Ibid.
[59] Ibid.
[60] Ibid.
[61] Ibid.
[62] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.

emissions by 1.2 to 4.4 percent, depending on the level of deployment.[63]

Several initiatives are underway to study the feasibility of converting from the traditional gas tax to mileage based fees. These studies recognize that a reduction in VMT and emissions are possible benefits of mileage based fees, but finding a better solution for financing transportation is the main goal. Examples of these studies are listed below.

- The University of Iowa is conducting the federally funded National Evaluation of a Mileage-Based Road User Charge study. The study seeks to evaluate the public response to instituting a mileage based fee to replace the existing gas tax. There are two goals: 1) Assess the reliability, security, flexibility, user friendliness and cost-effectiveness of the technology; and 2) Evaluate operator acceptance of the system. Six sites were chosen to be a part of the study: Albuquerque, New Mexico; Billings, Montana; Chicago, Illinois; Miami, Florida; Portland, Maine; and Wichita, Kansas. A final report on the findings of the study, sponsored by the U.S. DOT, is expected by the end of 2010.[64]
- The Puget Sound Regional Council in Washington State conducted a pilot to examine changes in traveler behavior due to variable road charges that are based upon road use. GPS tolling devices were placed in the vehicles of 275 volunteers. Road use fees were electronically deducted from pre-paid accounts based on the time, day, and type of road used. Researchers then compared driver behavior before and after the devices were installed to determine if the fees caused driving pattern changes. The study showed that mileage based fees changed driver behavior:
  - Vehicle trips were reduced by seven percent
  - VMT was reduced by 12 percent
  - Minutes driven per week were reduced by eight percent
  - VMT on toll roads was reduced by 13 percent.[65]
- The Oregon DOT launched a pilot in April 2006 to test the feasibility of the Oregon Road User Fee Task Force's mileage fee concept to replace the gas tax with mileage based fees that are collected at fueling stations. A device that counts the number of miles driven within defined zones was installed on each of the 285 vehicles participating in the pilot, and a congestion pricing zone was established. The fees were determined through GPS, read at the gas stations with specially equipped pumps, and then transmitted to a central database for application of the mileage fee rates. State fuel taxes were deducted from the per gallon price of fuel. The pilot proved that the concept is viable using existing technology and demonstrated a 22 percent reduction in driving during peak periods.[66]
- The Nevada DOT is conducting a VMT Fee Study to "explore and evaluate a replacement source of revenue for the current fuel taxes to continue to efficiently and effectively operate, maintain and improve the roads and highways in Nevada." The three-phased study will begin

[63] Transportation Research Board. (2009). *A Transportation Research Program For Mitigating and Adapting to Climate Change and Conserving Energy.* Washington, DC: National Academy of Science.
[64] University of Iowa. (2008). *Mileage-based Road User Charge Study FAQ's*. Retrieved December 16, 2010, from Road User Study: http://www.roaduserstudy.org/faq.aspx
[65] Puget Sound Regional Council. (2008). *Traffic Choices Study - In Summary.* Retrieved December 16, 2010, from Puget Sound Regional Council: http://www.psrc.org/assets/36/in-summary.pdf
[66] Whitty, J. M. (2007, November). *Road User Fee Pilot Program.* Retrieved December 16, 2010, from State of Oregon: http://www.oregon.gov/ODOT/HWY/RUFPP/docs/RUFPP_finalreport.pdf

with a VMT road user fee study for completion by the end of 2010, followed by technology testing and finalization of the Pilot Program Protocol in 2011, and finally, the pilot will be conducted and evaluated in 2012.[67]

- Citing "drastically fluctuating oil prices" and drivers who are "reducing fuel consumption by switching their principal vehicle, driving less or choosing more efficient vehicles," the Chairs of the California, Oregon, and Washington State Transportation Commissions sent a letter in 2009 to Congresswoman Maria Cantwell asking "Congress to confirm the feasibility of a VMT-based fee system by mandating the federal government to fully explore a transition from the gas tax to a funding system tied more directly to road use and impact on the road system." The Oregon and Washington State studies were referenced in the letter as demonstrating the feasibility of mileage based fees. The Chairs concluded from these studies that a "Vehicle Miles Traveled fee structure appears to nicely compliment several priorities shared amongst the West Coast States – namely: reducing congestion, reducing greenhouse gas emissions, increasing the use of alternative transportation modes, and identifying a sustainable, long-term transportation funding source."[68]

Driver acceptance of mileage based fees has not yet been determined. A number of states are interested in establishing the fees, and the technology exists to do so. Pilots for mileage based fees have demonstrated the ability for these applications to reduce VMT, which in turn can reduce fuel consumption and emissions.

3.2 Eco-Driving Applications

Applications that work to modify driver behavior can be an effective way to reduce fuel use and GHG emissions. This category includes initiatives such as eco-driving information and assistance, adaptive cruise control (ACC), and eco-driving navigation systems. These applications target individual drivers with the objective of promoting a driving style that lowers vehicle emissions. When the various applications are combined, they can potentially deliver up to a 20 percent reduction in fuel consumption, as well as a 20 percent reduction in CO_2 emissions.[69] Applications use both passive and active strategies.[70]

Several vehicle original equipment manufacturers (OEMs), such as Audi and Fiat, are interested in eco-driving applications and are performing pilots in Europe. Eco-driving assistance pilot projects have demonstrated the potential to reduce emissions by 3 to 15 percent.[71]

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[67] Nevada Department of Transportation. (2010). *Vehicle Miles Traveled Fee Study*. Retrieved December 16, 2010, from http://www.vmtfeenv.com/

[68] Chalker, J., Achterman, G., & O'Neal, D. (2009, January 16). *VMT fee urged by California, Oregon and Washington state transportation heads.* Retrieved December 16, 2010, from Toll Roads News: http://www.tollroadsnews.com/sites/default/files/WestOnVMT.pdf

[69] ERTICO ITS Europe. (2010, May 25). *eCoMove kicks off!* Retrieved December 17, 2010, from ERTICO ITS Europe: http://www.ertico.com/ecomove-kicks-off/

[70] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.

[71] ERTICO ITS Europe. (2010, May 25). *eCoMove kicks off!* Retrieved December 17, 2010, from ERTICO ITS Europe: http://www.ertico.com/ecomove-kicks-off/

3.2.1 Eco-Driving Information and Eco-Driving Assistance

Eco-driving information applications provide training programs or recommendations via an OBU to promote energy efficient driving techniques. These applications can include attaching the OBU to the controller area network (CAN) bus, a protocol that allows components of the vehicle's computer to communicate with each other, to provide real-time vehicle energy efficiency data (e.g., energy use and gear shift indicators). The on-board computer is the main piece of technology used for deploying eco-driving information applications. Practicing moderate levels of eco-driving alone has shown the potential for reducing emissions up to 15 percent.[72] However, applications that provide eco-driving information do not automatically reduce emissions. Drivers must actively engage and follow provided directions in order to reduce emissions.

Eco-driving assistance includes on-board applications that interact with transportation management systems, information networks, and traffic control systems to determine vehicle performance relative to prevailing traffic conditions. Drivers are provided with real-time feedback on various driving behaviors, such as traffic signal phase and timing (SPaT), speed advice, and enhanced map data announcing upcoming turns, ramps, and grade changes, to promote energy efficient driving practices. A signal controller, in-vehicle display, on-board computer, and wireless communications from the controller to devices are needed to deploy eco-driving assistance applications.

Governments, academia, and industry are all conducting research on the environmental benefits of eco-driving assistance and information applications. The European Commission (EC) sponsored the *Impact of Information on Communication Technologies on Energy Efficiency in Road Transport – Final Report*, which presents an analysis on how information and communications technologies can contribute to the reduction on CO_2 emissions and other GHGs.[73] The study estimated the environmental impacts of various strategies, including eco-driving assistance. The analysis found at the current European Union 27 (EU27)[74] level, and assuming 100 percent penetration of an in-vehicle system and driver compliance, eco-driving assistance has the potential to reduce road traffic CO_2 emissions by 5 to 15 percent. It specifically found that the fuel consumption and energy-use indicators gave drivers feedback that taught them to drive in a fuel efficient manner, and the gear shift indicator taught drivers to perform gear shifts at lower speeds resulting in deeper throttle positions that lead to increased energy efficiency.[75]

Nine European Union Member States (Austria, Finland, Czech Republic, Belgium, Poland, France, Greece, United Kingdom, and the Netherlands) collaborated to launch the ECODRIVEN campaign in September 2007. The purpose of the campaign is to "raise awareness of such environmentally-

[72] Audi of America. (2010, June 2). *Audi travolution: efficiently through the city*. Retrieved December 17, 2010, from Media Site: http://www.audiusanews.com/newsrelease.do;jsessionid=43C6207F9D63CA92A47BDCFA7E395DB3?id=1812

[73] European Commission. (2010). *About This Site*. Retrieved January 3, 2011, from European Commission: http://ec.europa.eu/about_en.htm

[74] EU-27 includes the following countries: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

[75] Klunder, G. A., Malone, K., Mak, J., Wilmink, I. R., Schirokoff, A., Sihvola, N., et al. (2009, September 16). *Impact of Information and Communication Technologies on Energy Efficiency in Road Transport- Final Report.* Retrieved December 19, 2010, from http://ec.europa.eu/information_society/activities/esafety/doc/studies/energy/energy_eff_study_final.pdf

friendly driving practices, which are known as 'eco-driving'" to at least 2.5 million drivers by the end of 2008. Five golden rules of eco-driving are shared with the drivers:

1. Change gears between 2,000 and 2,500 rpm and stay in as high a gear as possible.
2. Drive at a steady speed. This reduces fuel consumption since unnecessary acceleration uses a lot of fuel. Driving fast also uses much more energy: going at 120 kph increases fuel consumption for each kilometer driven by 30% compared with driving at 80 kph.
3. Anticipating traffic flow helps to avoid braking and accelerating excessively, and enables you to maintain a more steady speed.
4. Check tire pressure frequently. If your tires are under-inflated by 25%, resistance increases by 10% and fuel consumption by 2%.
5. Decelerate gradually by releasing the accelerator and staying in the same gear. This engages the engine's fuel cut-off mechanism, with the result that the car consumes practically no energy.

In addition to this initiative, the Netherlands has made eco-driving a required element of their drivers test.[76]

An academic research initiative conducted at the University of California (Berkeley and Riverside) used modeling and simulation to illustrate the impacts of an in-vehicle advanced driving alert system (ADAS) that provides real-time traffic signal status information to help drivers avoid hard braking at intersections. Time-to-red (TTR) information is communicated to instrumented vehicles, and on-board vehicle systems compare the signal's TTR with the estimated travel time to the signal and decide whether to issue alerts. The research found at a volume-to-capacity (v/c) ratio of 0.25 and a speed limit of 55 kilometers per hour (km/h) (34 mi/h), fuel consumption is reduced by 14 percent. At a v/c ratio of 0.7 and a speed limit of 60 km/h (37 mi/h), fuel consumption is reduced by 12 percent. It may not be necessary to reach a 100 percent penetration rate in order to realize benefits; however benefits are reduced when congested conditions persist (i.e., v/c ratios over 0.8). Future research may include:

- Study of benefits of vehicles that are not instrumented with ADAS adjusting speeds according to ADAS-instrumented vehicles in front;
- Extension of simulation to a larger traffic network with all approaches of traffic flows at the intersections;
- Sensitivity analysis of parameters used in the algorithms such as the DSRC communication range;
- Development of more sophisticated ADAS by accounting for real-time traffic conditions either through loop detectors or inter-vehicle communications;
- Quantification of the impacts of the proposed ADAS on other traffic performance measures (e.g. delays);
- Comparison of the energy and emission benefits from ADAS with those from dilemma control strategies; and
- Field implementation to validate the proposed ADAS.[77]

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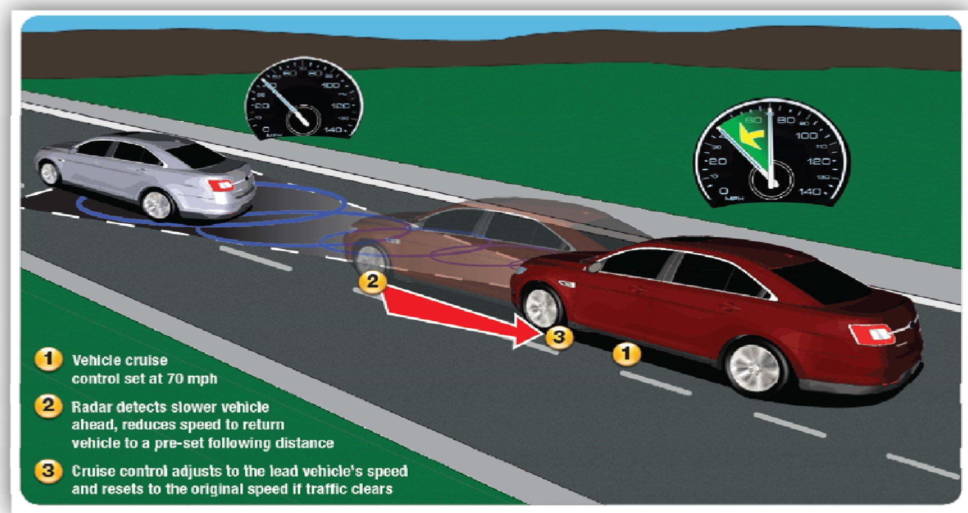
[76] European Commission. (n.d.). *Reducing fuel consumption through eco-driving*. Retrieved December 2, 2010, from http://ec.europa.eu/clima/sites/campaign/news/news10_en.htm

Within the automotive industry, Audi is conducting eco-assistance and information pilots. Audi's Travolution Project includes 15 test vehicles that communicate in real time with 150 traffic signals in Ingolstadt, Germany. Each signal continuously transmits a status report to the vehicles involved in the pilot regarding the color of each traffic signal and preview of how the signals will likely change in the near future. A dashboard mounted display relays real-time data to drivers, including: speed to drive the "green wave," status of approaching signals, length of time before the signal turns green, and congestion information. A 2006 pilot demonstrated a reduction of 17 percent in fuel consumption, saving an estimated 700,000 liters (184,920 US gallons) of fuel. The Travolution system can reduce fuel consumption by 0.02 liter for every traffic signal stop and subsequent acceleration phase that can be avoided. When this reduction is multiplied by the number of signals approached and vehicles, the potential fuel savings are substantial. If the system is deployed throughout Germany, which has 60,000 traffic signals, CO_2 emissions could be reduced up to 15 percent, or 2 million MTCE. An additional Travolution Project pilot is currently underway in Danube, Germany.[78]

3.2.2 Adaptive Cruise Control (ACC)

ACC is another type of eco-driving application. ACC works like conventional cruise control, allowing the driver to set the desired speed, but it also adjusts the vehicle speed to the preceding vehicle to maintain a predefined following distance, as shown in Figure 3-2 below.



[77] Wu, G., Boriboonsomsin, K., Zhang, W., Li, M., & Barth, M. (2010). Energy and Emission Benefit Comparison between Stationary and In-Vehicle Advanced Driving Alert Systems. *TRB 2010 Annual Meeting.* Washington, DC: TRB.
[78] Audi. (2010, June 2). *Audi travolution: efficiently through the city*. Retrieved December 29, 2010, from Audi of America Media Site: http://www.audiusanews.com/newsrelease.do;jsessionid=4E9B2DCB47182D57B7189CEFE8FDED96?id=1812

Figure 3-2. Adaptive Cruise Control[79]

ACC is not a new concept. In fact, several vehicle manufacturers offer ACC systems in their vehicles today. A brief summary of ACC systems is provided below:

- In 1995, Mitsubishi was the first OEM to offer a laser-based ACC system on the Japanese Diamante. This system used laser radar sensors installed on the front bumper to detect preceding vehicles in the lane and the "system controls the engine power and gear to follow behind the vehicle in front at a safe distance. The driver is alerted with sound and lights if the two cars come too close. The vehicle returns to the initially set velocity when the forward vehicle moves out of the lane or increases its speed." [80]
- Toyota offered its first "radar cruise control" system in 1997 on the Celsior, and added brake control and a low speed tracking mode that detected a stopped vehicle ahead in later years.[81] Toyota's "all-speed tracking function" system "monitors the preceding vehicle, maintaining the same distance behind it according to the other vehicle's speed, over a wide range of speeds up to 100km/h [about 62 mi/h]." The system also ensures the driver maintains a safe distance when the preceding vehicle comes to a stop, which can lessen "driver burden when the vehicle is in a stop-and-go situation during traffic congestion."[82]
- Mercedes first introduced Distronic in 1998, and today offers Distronic Plus with Pre-Safe® as an option. Distronic Plus is a radar-based cruise control that "monitors the vehicle ahead and adjusts speed to help maintain a chosen following distance." The system is able to slow down or stop the vehicle if traffic slows down or stops and then automatically accelerates when traffic does. The Pre-Safe Brake system "automatically engages up to 40% of available braking power and primes the brakes to deliver full power the moment you step on the brake pedal. If the brakes have not been applied within 0.6 seconds of a calculated impact, PRE-SAFE Brake will automatically engage them at 100% power. As an added safety precaution, a Proximity Warning System will issue an audiovisual warning if the calculated closing speed indicates that insufficient braking power has been applied by the driver."[83]
- In 2005, Acura introduced ACC integrated with a Collision Mitigation Braking System (CMBS) as an option. [84] Today, the system is available on the Acura MDX and ZDX. The ACC system allows the driver to set a desired speed and time intervals (short, medium, and long) from the preceding vehicle car and provides cruise control even in light traffic conditions. ACC "will maintain the set distance, modulating the throttle and applying moderate braking if

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[79] Ford Motor Company. (2009, December). *Adaptive Cruise Control and Collision Warning with Brake Support.* Retrieved December 19, 2010, from http://media.ford.com/images/10031/Adaptive_Cruise.pdf
[80] Highway Industry Development Organization (Japan). (2000, November). *Preview Distance Control (Mitsubishi Motors Corporation; DIAMANTE)*. Retrieved December 29, 2010, from Highway Industry Development Organization: http://www.hido.or.jp/ITSHP_e/wi/itshb/Preview.htm
[81] Treece, J. B. (1997, August 4). Toyota offers radar on Japan's Celsior. *Automotive News* .
[82] Toyota Motor Corporation Global. (2010). *ITS Based Approach*. Retrieved December 29, 2010, from Toyota Motor Corporation Global: http://www.toyota-global.com/innovation/intelligent_transport_systems/itbs_ap/comfort/
[83] Mercedes-Benz USA. (2010). *DISTRONIC PLUS Package*. Retrieved December 29, 2010, from Mercedes-Benz USA: http://www.mbusa.com/mercedes/vehicles/explore/packages/feature/class-E/model-E350C/groupId-af08c606a2a69210VgnVCM1000007c184335____/id-8a4e428682079210VgnVCM1000007c184335____
[84] Honda. (2006). *2006 Acura RL - Safety* . Retrieved December 29, 2010, from Acura Media News Room: http://www.hondanews.com/channels/280/releases/1eade13f-0196-cb92-225f-20004c34c1bd

necessary."[85] The CMBS system uses a radar transmitter mounted in the front bumper to evaluate the distance and closing speed of the preceding vehicle. CMBS phases in a series of alerts and braking actions depending on a driver's reaction when the system detects a collision may occur. "When the system senses that a frontal collision is unavoidable, and even if no prior alerts have been given, the front seat belts tighten, and strong braking is automatically applied to help reduce the impact velocity and collision force."[86]

- BMW's Active Cruise Control with Stop & Go function is available on the 5 Series Sedan. The Active Cruise Control "automatically reduces your speed if a slower vehicle appears in the lane ahead and then accelerates back to cruise speed when the lane is free." The Stop & Go system "will brake to a standstill if required, then sets off again when the traffic ahead moves. If the standstill is longer than three seconds, a touch on the accelerator is needed to set the 5 Series off again."[87]
- ACC is an available option on several Ford vehicles, including the 2010 Ford Taurus, 2010 Lincoln MKT, and 2010 Lincoln MKS. Ford plans to offer the option on the next generation Explorer, Ford Edge, and Lincoln MKX vehicles.[88]

ACC pilot projects have captured the environmental benefits of the application. Examples are summarized below:

- Rotterdam, The Netherlands: ACC reduced CO_2 and NO_x by three percent, but increased PM10 by three percent.[89]
- Southeast Michigan: ACC tests with 108 non-professional drivers reduced fuel consumption by 10 percent compared to manual driving.[90]
- California: An ACC simulation between Palo Alto and San Jose reduced fuel consumption by five to seven percent.[91]

Additionally, a 2001 study by the University of Southern California and Real-Time Innovations, Incorporated on the *Evaluation of the Environmental Effects of Intelligent Cruise Control (ICC) Vehicles* yielded promising results. The study used field experiments and simulation models to quantify the environmental benefits of ACC-enabled vehicles. Field tests were conducted using one ACC-enabled vehicle and two other manually operated vehicles in a single lane of freeway traffic.

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[85] Acura. (2010). *Adaptive Cruise Control*. Retrieved December 29, 2010, from Acura: http://www.acura.com/Features.aspx?model=MDX&modelYear=2011&context=Exterior#adaptive_cruise_control

[86] Acura. (2010). *Collision Mitigation Braking System*. Retrieved December 29, 2010, from Acura: http://www.acura.com/Features.aspx?model=MDX&modelYear=2011&context=Safety+_+Security#collision_mitigation_braking_system

[87] BMW. (2010). *From zero to 180 km/h: Active Cruise Control with Stop & Go function on the BMW 5 Series Sedan*. Retrieved December 29, 2010, from BMW: http://www.bmw.com/com/en/newvehicles/5series/sedan/2007/allfacts/ergonomics/acc_stop.html

[88] Ford Motor Company. (2009, December). *Adaptive Cruise Control and Collision Warning with Brake Support.* Retrieved December 19, 2010, from http://media.ford.com/images/10031/Adaptive_Cruise.pdf

[89] Mahmod, M., van Arem, B., Pueboobpaphan, R., & Igamberdiev, M. (2009). Modeling reduced traffic emissions in urban areas: the impact of demand control, banning heavy duty vehicles, speed restriction and adaptive cruise control. *TRB 2010 Annual Meeting.* Washington, DC: TRB.

[90] National Research Council. (2010). *Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles.* Washington, DC: The National Academies Press.

[91] Ibid.

During the field trials, driver responses and vehicle dynamics were recorded as they followed a lead vehicle with a pre-programmed speed profile (aggressive-rapid-acceleration or smooth-acceleration). The ACC-enabled vehicle trailed the other vehicles at different positions and implemented a smoothing effect to decrease the variance between the acceleration and deceleration extremes exhibited by the manually operated vehicles. Information from each field test was then input into a simulation model to measure net changes in fuel consumption and emissions.[92] The Comprehensive Modal Emissions Model (CMEM) 1.00 developed by the University of California-Riverside was used to analyze and calculate pollution and fuel consumption estimates. The CMEM model quantified tailpipe emissions based on second-by-second velocity, acceleration, and grade changes for each individual vehicle. Emissions measured included unburned HC, CO, CO_2, and NO_x. Results shows that the smoothing of traffic flow by the ACC-enabled vehicle significantly reduced emissions and the fuel consumption of manual traffic. Field studies demonstrated reductions of CO up to 19.2 percent, CO_2 up to 3.4 percent, and NO_x up to 25.7 percent.[93]

3.2.3 Eco-Driving Navigation Systems

Over the past decade, on-board and portable navigation systems have frequently been purchased and used by drivers to assist with driving directions and routing around congestion. Navigation systems depend on a digital map of the road network and use GPS technology to acquire the location of the user. Some navigation systems provide traffic and incident-related information to affected motorists. Combining navigation systems and traveler information can create powerful tools to assist drivers in reducing fuel consumption and vehicle emissions. It should be noted that eco-driving navigation systems do not passively reduce emissions; drivers must actively engage and follow the provided directions in order to reduce vehicle emissions.[94]

Navigation systems can provide substantial benefits for fuel economy and environmental impacts. According to an EC report, drivers using in-vehicle and portable navigation systems in unfamiliar locations can reduce VMT by 16 percent, and drivers can save up to 30 percent in mileage searching for a parking space, if the appropriate information is provided by the system. Fuel consumption and time savings are realized using real-time traffic information that helps drivers avoid traffic jams. These reductions all add up to emissions saving, particularly when supported by intermodal information.[95]

Eco-routing features, designed to guide drivers on more fuel efficient routes, are now being incorporated into navigation systems. Such tools range from an indicator that highlights optimal fuel efficiency, to sophisticated eco-routing functions that employ real-time traffic data or roadway data to suggest the most efficient path to a destination based on current driving conditions. It is possible to use a “routing algorithm that optimized a journey for fuel economy or least environmental impacts.”[96]

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[92] Bose, A., & Ioannou, P. (2001). Evaluation of the Environmental Effects of Intelligent Cruise Control (ICC) Vehicles. *80th Annual Transportation Research Board Meeting.* Washington, D.C.: Transportation Research Board.
[93] Ibid.
[94] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.
[95] Kompfner, P., & Reinhardt, W. (2008). *ICT for Clean & Efficient Mobility: Final Report.* Brussels: European Commission.
[96] Ibid.

Several barriers need to be addressed before such routing algorithms can be deployed confidently. Environmental data, alternative modes, and parking availability information are not always available or integrated into navigation systems. Traffic data is often incomplete or inaccurate and is not always provided free of charge. Addressing these barriers is important for leveraging navigation systems as a means to reduce vehicle emissions. [97]

Advances are being made, however. For example, Garmin's nüvi includes an ecoRoute feature that helps motorists save money on fuel costs by finding more fuel-efficient routes. These routes are selected by factoring in fuel consumption data, the number of stops, speed limits, and other factors. This ecoRoute feature also gives motorists real-time feedback on the efficiency of their driving.[98]

According to a recent Ford press release, the new MyFord Touch technology, which allows drivers to execute various commands by voice or touchscreen interaction, will allow drivers to choose an "Eco-Route" option on the navigation system for greener driving. "Eco-Route is not necessarily the fastest or shortest route but is the most fuel efficient. Typically, it charts a course that avoids congested freeways while maximizing the use of major roads where the driver can maintain an efficient rate of speed. When Ford of Europe engineers tested the feature, they achieved up to a 15 percent improvement in fuel economy using the Eco-Route." The system uses "historical and real-time traffic data as well as posted speed information to calculate" the greenest route.[99]

Another example of an eco-driving navigation system application is Blue&Me, a joint venture by Fiat, TomTom, and Microsoft. Blue&Me integrates portable devices, like mobile phones, into the vehicle environment, and voice command systems are completely integrated into the steering wheel controls and information display.[100] The associated TomTom navigation device is available only on select Fiat models (Punto Evo and New Doblo models).[101] Blue&Me enables drivers to minimize their impact on the environment. The technology collects vehicle efficiency data through an on-board Universal Serial Bus (USB) key. Drivers remove the USB key and review driving data on their home personal computer. Through the online *Eco:Drive* computer application, drivers are presented with detailed information on the environmental performance of their vehicle and their driving techniques. For example, drivers can review the CO_2 emissions generated for each trip and are given an *Eco:Index* score on a scale of 100, as shown in Figure 3-3.[102]

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[97] Kompfner, P., & Reinhardt, W. (2008). *ICT for Clean & Efficient Mobility: Final Report.* Brussels: European Commission.
[98] Garmin. (2010). *Garmin: ecoRoute*. Retrieved December 29, 2010, from http://www8.garmin.com/buzz/ecoroute/index.html?lang=en
[99] Ford Motor Company. (2010). *New MyFord Touch 'Coaches' Drivers to Improve Fuel Efficiency;Navigation Adds Eco-Route Feature*. Retrieved December 29, 2010, from Ford: http://media.ford.com/article_display.cfm?article_id=32418
[100] Damiani, S., Deregibus, E., & Andreone, L. (2009). Driver-vehicle interfaces and interaction:where are they going? *European Conference of Transport Research Institutes* (pp. 87-96). Springer.
[101] Fiat. (2010). *Fiat Blue&Me TomTom Sat Nav*. Retrieved December 19, 2010, from http://www.fiat-accessories.com/Fiat-TomTom-Sat-Nav
[102] Damiani, S., Deregibus, E., & Andreone, L. (2009). Driver-vehicle interfaces and interaction:where are they going? *European Conference of Transport Research Institutes* (pp. 87-96). Springer.

Figure 3-3. Blue&Me Eco:Drive Application[103]

The Blue&Me *Eco:Drive* system also analyzes driving style and provides recommendations for efficiency, such as whether or not the driver is making efficient gear changes. This solution "demonstrates the possible measures that OEMs can undertake to reduce the level of CO_2 emissions are not only limited to the design of novel or optimized engines based on existing or on alternative energy sources, but can be extended to telematics applications."[104] While Blue&Me does not provide real-time recommendations, it is possible that it, and other similar applications, could do so with deployment of the appropriate technology.

The University of California, Riverside, and the University of California, Berkeley, are working with Audi on the *Clean Air - A Viable Planet Initiative* to develop an eco-friendly navigation system. The research at these academic institutions demonstrates the

> *…use of advanced traffic information and network connectivity to produce significant fuel savings…advances in networking and computer processing power are allowing the researchers to build an integrated, dynamic database of regional traffic activity. This enables drivers to select not just the fastest route in time, or the shortest route in distance, but now also the least fuel consumed, or even the least pollution emitted…the key to this technology is the ability to combine traffic data from freeways and arterial roads, bringing together existing vehicle sensors with traffic signal information, vehicle-based GPS sensors, and broadband wireless communications. With multivariate, real-time information available, the researchers can reliably predict traffic patterns using a data fusion model based on microscopic flow traffic theory.*[105]

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[103] Fiat. (n.d.). *Eco:Drive*. Retrieved December 19, 2010, from http://www.fiat.co.uk/ecodrive/
[104] Damiani, S., Deregibus, E., & Andreone, L. (2009). Driver-vehicle interfaces and interaction:where are they going? *European Conference of Transport Research Institutes* (pp. 87-96). Springer.
[105] University of California, Riverside. (2010). *Center for Environmental Research and Technology*. Retrieved December 29, 2010, from http://www.cert.ucr.edu/

3.3 Logistics and Fleet Management Applications

Logistics and fleet management of vehicle fleets includes a range of functions, such as vehicle maintenance, vehicle telematics, driver management, speed management, fuel management, and health and safety management. Applications in this category include: Automated Vehicle Location (AVL) systems; commercial fleet management systems; and parking/loading/delivery management.[106]

3.3.1 Automated Vehicle Location (AVL) Systems

AVL is a "fleet management tool that allows a fleet manager to monitor the fleet-vehicles' location at any given time…AVL technology has been widely used by the trucking industry and, to some extent, by the transit and emergency management."[107] AVL can assist individual commercial or transit vehicles with increasing efficiency and can include real-time transit vehicle arrival and departure information for travelers.[108] AVL involves the use of GPS, radio receivers, and sensor technologies coupled with complementary software.[109]

AVL systems have the potential to reduce GHG emissions. For example, an investigation was performed on a single bus route in Minneapolis-St. Paul using AVL to identify route optimization opportunities. Metro Transit, the local transit authority in the Minneapolis Twin Cities region, has been testing various ITS applications since 1999. Metro Transit fully implemented an AVL system and archiving system and partially implemented an automatic passenger counter (APC) system in 2005, and these systems were used "to analyze the performance of a problematic bus route (Route 17) in the Metro Transit system." A methodology was used to determine how various performance measures and indicators can be obtained from archived ITS data. The methodology includes multiple approaches to displaying ITS data within a Geographic Information Systems (GIS) environment to allow visual identification of problem areas along routes. The generated models showed a number of opportunities for optimization, including that schedule revisions are needed to Route 17 in terms of running time. The study found that it was also "clear from the analysis that many scheduled stops along this route are underutilized and revisions in stop spacing, accompanied by careful consolidations are recommended." While environmental impacts were not a focus of this study, the

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[106] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.
[107] U.S. Department of Transportation. (2004, January). *AVL technologies for highway maintenance activities, particularly snow removal, cost approximately $3,500 per fleet vehicle*. Retrieved January 5, 2011, from ITS Costs Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ID/96062B55973E5190852573E900557827?OpenDocument&Query=CApp
[108] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.
[109] U.S. Department of Transportation: Research and Innovative Technology Administration. (2006, September). *Costs data available for several advanced winter maintenance technologies: automatic vehicle location (AVL) range from $1,250 to $5,800 per vehicle...* Retrieved December 2, 2010, from ITS Costs Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/E8F3B051DBDBF5CE852573E9004BDCB3?OpenDocument&Query=Home

data collected from the AVL systems was used to optimize the bus route, which can lead to reduced delays, a more efficient route, and reduced GHG emissions.[110]

3.3.2 Commercial Fleet Management Services

Commercial fleet management services assist fleets with scheduling and logistics support and can include eco-criteria. A wide variety of technologies can be used in the delivery of commercial fleet management services and the technologies utilized are dependent upon the level of services acquired. Examples of technologies that can be used include: eco-driving training; idle reduction solutions; software that monitors real-time fuel economy and vehicle location; and mobile communications systems.[111]

Eco-driving training campaigns "target individual drivers with the objective of promoting a driving style with lower CO_2 emissions. The strategy can be supported by internet-based and/or on-board instruments, as well as systems and tools embedded in the vehicle itself." Eco-driving training can also be deployed through classroom and in-person training methods. The environmental benefits of eco-driving occur immediately after the training is deployed and fuel economy improves between five and 15 percent.[112]

It is currently unknown whether the strategy continues to impact driver behavior and if the environmental benefits continue in the long term. It can be difficult to keep the habit long after the training is completed. However, the Research Findings from the 2008 International Transport Forum suggest that there are methods to ensure the habits continue in the long term.

> *In-car equipment such as gear shift indicators, cruise controls and on-board computers giving feedback on fuel consumption help improve fuel economy. Instrumentation alone can deliver around five percent savings and provide an incentive to maintain and even improve driver performance after training. Cars are increasingly equipped with on-board computers that have an instantaneous fuel consumption readout function. Making this the default display would be a cheap and effective way to promote fuel-efficient driving. Introducing more advanced technology to run cars in an eco-driving mode as standard could achieve significant fuel savings.*[113]

In one example, the Nevada DOT contracted with a commercial fleet management service to conduct a pilot project in 2010 that monitored driver behavior. The service provider installed monitoring equipment on cars, pickup trucks, plow trucks, and other medium duty vehicles. Driver behavior was

[110] El-Geneidy, A., Horning, J., & Krizek, K. J. (2007). *Using Archived ITS Data to Improve Transit Performance and Management.* St. Paul: Minnesota Department of Transportation.
[111] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.
[112] Ibid.
[113] Organization for Economic Cooperation and Development/International Transport Forum. (2008). Transport and Energy: The Challenge of Climate Change Research Findings. *International Transport Forum Leipzig 2008*, (p. 13).

recorded, the equipment uploaded data to a central database, and reports on individual drivers were created to identify drivers in need of remedial training.[114]

Classroom or in-person eco-driving training principles provided through commercial fleet management services can be incorporated into on-board computers, and ITS applications could provide real-time recommendations to drivers based upon real-time performance information collected through V2I communications.

Another commercial fleet management application that provides environmental benefits is idle reduction solutions for trucking fleets. These solutions range from stand-alone devices to components that can be integrated into the vehicle design. Idle-off stop-start systems for cars offer up to 20 percent emission reductions opportunities for urban driving conditions. In Europe, these systems add approximately €600 to the vehicle price.[115] One stand-alone service in the United States, IdleAire, has proven effective for reducing emissions from long haul trucking fleets during driver resting periods. Through a built in touch-screen computer device (as shown below in Figure 3) that attaches to the vehicle through a window adapter that allows the device to securely fit on the vehicle, the service provides filtered heating and air conditioning, electrical outlets, and communications (Internet, telephone, and television), which allows the driver to turn off the vehicle engine instead of idling the vehicle during rest stops.[116]

Over 50 million gallons of diesel fuel have been saved through the use of IdleAire, preventing over 1.1 billion pounds of emissions and eliminated 519,000 MTCE. After accounting for the electricity used to power the service device, the system provides an overall 83 percent net emissions reduction compared to idling the vehicle.[117] While IdleAire does not currently employ ITS technology, there are potential future applications. For example, real-time traffic data could be deployed through the IdleAire service module so that drivers could select the best route to their next location. ITS applications, such as eco-navigation systems, could provide trucking fleets with locations and routes to a rest stop that has an idle reduction device.

[114] Gallivan, F. (2010). *Greenhouse Gas Mitigation Measures for Transportation Construction, Maintenance, and Operations Activities.* ICF International, prepared for AASHTO Standing Committee on the Environment.
[115] Organization for Economic Cooperation and Development/International Transport Forum. (2008). Transport and Energy: The Challenge of Climate Change Research Findings. *International Transport Forum Leipzig 2008*, (p. 26).
[116] IdleAIR. (1, December 2010). *IdleAIR, Inc., the in-cab services leader*. Retrieved December 7, 2010, from http://www.idleaire.com/
[117] Ibid.

Figure 3-4. IdleAire Device[118]

Emissions reductions from a commercial fleet management service were shown in Napa, California. The City of Napa uses an On-Board Diagnostics II (OBD-II) technology commercial fleet solution, Networkfleet, to provide the City's fleet managers with real-time location and utilization information. [119] In addition to the AVL, the OBD-II "monitors virtually every component that can affect the emission performance of the vehicle to ensure that the vehicle remains as clean as possible over its entire life, and assists repair technicians in diagnosing and fixing problems with the computerized engine controls."[120] The Clean Air Act Amendments of 1990 required that all 1996 and beyond model year light-duty vehicles and trucks be equipped with OBD-II. [121] The Networkfleet technology was originally purchased for odometer readings, but the City of Napa extended the use for collecting vehicles' diagnostic trouble codes and "monitoring excessive idling, vehicle utilization after work hours and mileage discrepancies." The technology, which merges GPS with the cellular network, even provides continuous monitoring of vehicle emissions, which has allowed the City of Napa to join California's Continuous Testing Program (CTP) and therefore save approximately $3,500 annually because vehicles registered in CTP are exempt from annual smog checks. In addition to the cost savings, the City of Napa has been able to reduce more than 44,000 pounds of GHG emissions annually.[122]

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[118] IdleAIR. (1, December 2010). *IdleAIR, Inc., the in-cab services leader*. Retrieved December 7, 2010, from http://www.idleaire.com/

[119] Networkfleet. (2010, July 21). *Networkfleet Helps City of Napa Monitor Fleet Operations-Improving Vehicle Maintenance while Decreasing Fleet Costs.* Retrieved December 2, 2010, from Network Fleet: Case Studies: http://info.networkfleet.com/rs/networkfleet/images/Networkfleet_City_of_Napa_Case_Study.pdf

[120] U.S. Environmental Protection Agency. (2009, November 18). *On-Board Diagnostics: Basic Information*. Retrieved December 29, 2010, from http://www.epa.gov/otaq/regs/im/obd/basic.htm

[121] Ibid.

[122] Networkfleet. (2010, July 21). *Networkfleet Helps City of Napa Monitor Fleet Operations-Improving Vehicle Maintenance while Decreasing Fleet Costs.* Retrieved December 2, 2010, from Network Fleet: Case Studies: http://info.networkfleet.com/rs/networkfleet/images/Networkfleet_City_of_Napa_Case_Study.pdf

3.4 Traffic Management and Control Applications

Traffic management applications provide the ability to analyze current traffic conditions and dynamically adjust to accommodate different types of traffic or changing conditions. Advanced traffic management applications "seek not only to increase throughput and reduce congestion, but can be designed to promote optimum speeds for energy efficiency, reduce 'stop & go' behaviour [sic], and so on."[123]

Applications discussed in this category include: adaptive signal control; incident management; ramp metering; speed management; and traffic signal optimization/coordination; integrated corridor management (ICM), and active traffic management strategies. In general, the traffic signal applications have high rates of return on investment.[124]

3.4.1 Incident Management

Incident management is the systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of accidents, and improve the safety of motorist, crash victims, and incident responders.[125] Incident management can reduce the effects of incident-related congestion by decreasing the time to detect incidents, the time for responding vehicles to arrive, and the time required for traffic to return to normal conditions. Integrating traveler information with incident management systems can reduce emissions an additional 3 percent and improve fuel economy by 1.5 percent.[126] Incident management systems can require the use of several technologies:

- Detection equipment.
- Closed circuit television (CCTV) cameras.
- Dynamic message signs (DMS).
- Safety service patrols.

NaviGAtor, the incident management program in Georgia, led to a reduction in fuel consumption and emissions. The program saved 6.83 million gallons of fuel annually and assisted in reducing CO by 2,457 tons, HC by 186 tons, and NO_x by 262 tons.[127]

Additional benefits can be achieved by integrating traveler information with traffic and incident-management systems, with emissions reductions up to three percent and more than one percent improvement in fuel economy.[128]

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[123] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.
[124] Birdsall, M. (March 2010, March 2010). Gas Fizzling: ITS are useful tools to weaken greenhouse-gas emissions. *Roads and Bridges* , pp. 32-34.
[125] U.S. Department of Transportation. (2000). *Traffic Incident Management Handbook.* Retrieved November 23, 2010, from Federal Highway Administration: http://ops.fhwa.dot.gov/eto_tim_pse/faq/hand.htm
[126] Birdsall, M. (March 2010, March 2010). Gas Fizzling: ITS are useful tools to weaken greenhouse-gas emissions. *Roads and Bridges* , pp. 32-34.
[127] Ibid.
[128] Ibid.

Maryland's State Highway Administration established a highway incident management program, the Coordinated Highways Action Response Team (CHART), in the mid-1980s. A performance evaluation of CHART in 1997 documented resulting benefits for assistance to drivers, reduction in secondary incidents, reduction in driver delay time, and reduction in fuel consumption. All of these benefits can also contribute to emissions reductions.

- *Assistance to Driver:* CHART averaged 25.6 minutes for each instance of documented driver assistance. However, the majority of CHART's assistance to drivers did not require major efforts and were not documented, and these prompt responses minimized potential rubbernecking effects from drivers, and therefore potentially eliminate numerous incidents of excessive delay. By reducing excessive delays, fuel consumption and emissions are also reduced.
- *Reduction in Secondary Incidents:* Secondary incidents were defined in this evaluation as "the number of incidents occurred within two hours after a major incident and within the range of two miles." A reported 625 secondary incidents were reported, and an estimated 962 secondary incidents would have occurred without CHART in place. Therefore, it is estimated that CHART potentially eliminated 337 secondary incidents, and reduced travel time, fuel consumption, and emissions that would have occurred.
- *Reduction in Driver Delay Time:* It was estimated that CHART reduced driver delays by approximately 35 percent, reducing an estimated 44.68 million vehicle-hours to 29.04 million vehicle-hours. When delays are reduced, emissions are also reduced. The estimated time savings adds up to a savings of $224.23 million to Maryland drivers, based upon the average hourly income of $14.34 per hour.
- *Reduction in Fuel Consumption:* During 1997, an estimated 5.85 million gallons of fuel were saved due to the CHART program, and therefore, it can be reasonably assumed that emissions reductions were also achieved, although no reliable emissions data were presented in the evaluation. Assuming an average price of $1.00 per gallon for gasoline in 1997, the CHART program saved Maryland drivers $5.85 million.[129]

Reductions in incident-related delay also led to fuel savings and related emission reductions. A simulation study of the San Antonio, Texas, TransGuide system of freeway and incident management found the system saved an average of 2,600 gallons of fuel per major incident.[130]

Additional benefits experienced from implementing incident management strategies are summarized below:

- In Broward County, Florida, "the 2006 analysis of the SMART SunGuide Transportation Management Center (TMC) roadway clearance time [the time between awareness of an incident and restoration of lanes to full operational status] and incident clearance time [the time between awareness for an incident and removal of all evidence of the incident, including

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[129] Chang, D. G.-L., Shrestha, D., & Point-Du-Jour, J. Y. (2000, May). *Performance Evaluation of CHART, An Incident Management Program, in 1997: Final Report.* Retrieved November 23, 2010, from Research and Innovative Technology Adminstration, National Transportation Library: http://ntl.bts.gov/lib/jpodocs/repts_te/13135.pdf

[130] Henk, & Molina. (1997). Before-and-After Analysis of the San Antonio TransGuide System. *76th Annual Meeting of the Transportation Research Board.* Washington, DC: Transportation Research Board.

debris or remaining assets, from shoulders as well as disabled and abandoned vehicles] showed reductions of 18% and 4%, respectively" when compared to 2005 data. [131]

- In "fiscal year 2008/2009, the Miami-Dade Traffic Incident Management (TIM) Team reduced the average roadway clearance time by 11% from the previous year."[132]

These benefit examples show reductions in clearance time, which can reduce vehicle idling, and therefore emissions.

3.4.2 Integrated Corridor Management (ICM)

ICM is the "coordination of transportation operations to improve travel management."[133] The U.S. DOT's ICM initiative "aims to enable corridor managers and operators to optimize the use of ITS infrastructure assets. The corridor-wide approach is designed to improve travel time reliability and predictability and to help manage congestion and empower travelers through better information and more choices."[134]

The efforts to date to reduce surface transportation congestion have focused on optimization of individual networks. Corridors offer an opportunity to operate and optimize the entire system as opposed to the individual networks. Through the Integrated Corridor Management Systems initiative, the U.S. DOT will provide guidance to assist agencies in implementing Integrated Corridor Management, create supporting analysis tools, approaches, and technical standards, and demonstrate the value of ICM.

The combined application of technologies and a commitment of network partners to work together have the potential to transform the way corridors are operated and managed. Thanks to recent advancements in intelligent transportation systems technologies, there is a tremendous opportunity today to integrate operations to manage total corridor capacity.

With ICM, the various institutional partner agencies manage the transportation corridor as a system-rather than the more traditional approach of managing individual assets, as shown in Figure 3-5. They manage the corridor as an integrated asset in order to improve travel time reliability and predictability, help manage congestion and empower travelers through better information and more choices.

[131] U.S. Department of Transporation. (2007, January). *In Broward County, Florida, the 2006 analysis for the SMART SunGuide TMC roadway and incident clearance times showed reductions of 18 percent and 4 percent respectively over 2005*. Retrieved December 29, 2010, from ITS Benefits Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/14A5B97DD8FD5265852576010066D000?OpenDocument&Query=BApp

[132] U.S. Department of Transportation. (2009). *In fiscal year 2008/2009, the Miami-Dade Traffic Incident Management (TIM) Team reduced the average roadway clearance time by 11 percent from the previous year*. Retrieved December 29, 2010, from ITS Benefits Database: http://www.itslessons.its.dot.gov/its/benecost.nsf/0/65CC5A13653E251D852577740054CFA7?OpenDocument&Query=BWhatsNew

[133] Cronin, B., Mortensen, S., Sheehan, R., & Thompson, D. (2010, December). *Integrated Corridor Management*. Retrieved January 3, 2011, from U.S. DOT Federal Highway Administration: http://www.fhwa.dot.gov/publications/publicroads/10novdec/02.cfm

[134] U.S. Department of Transportation. (2009, August 24). *Integrated Corridor Management Systems Program Plan*. Retrieved December 29, 2010, from FHWA Corporate Research and Technology: http://www.fhwa.dot.gov/crt/roadmaps/icmprgmplan.cfm

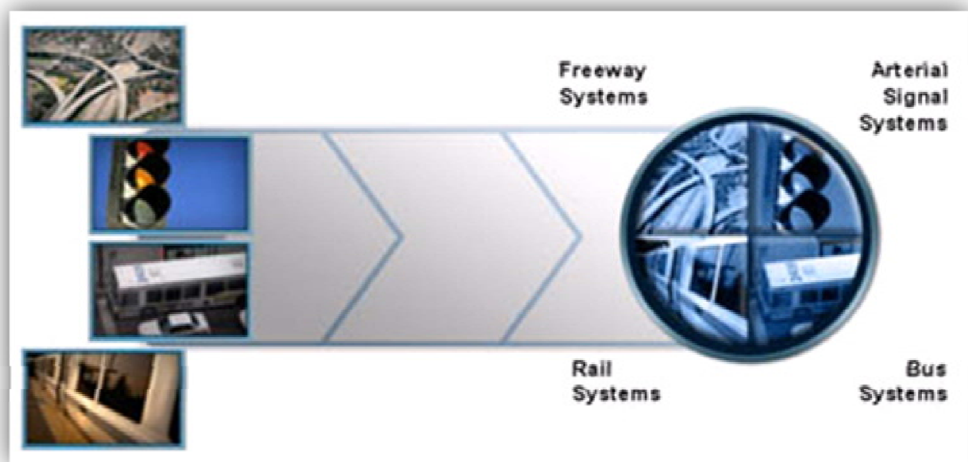

Figure 3-5. Integrated Corridor Management (ICM) [135]

In an ICM corridor, because of proactive multimodal management of infrastructure assets by institutional partners, travelers could receive information that encompasses the entire transportation network. They could dynamically shift to alternative transportation options-even during a trip-in response to changing traffic conditions. For example, while driving in a future ICM corridor, a traveler could be informed in advance of congestion ahead on that route and be informed of alternative transportation options such as a nearby transit facility's location, timing and parking availability.

In 2006, U.S. DOT selected eight ICM Test Corridors, including the I-880 corridor in Oakland, California. The corridor is located between Oakland and Fremont, California, and covers approximately 34 miles (250 lane miles) and contains a network of various routes and transit options, including bus and rail. An Analysis, Simulation, and Modeling (AMS) framework was developed to evaluate the impacts of the ICM strategies employed in the corridor. The model "examined recurring and non-recurring operational conditions using three levels of analysis: macroscopic, mesoscopic, and microscopic. The AMS framework analyzed the following ICM strategies:

- Zero ITS (baseline)
- Traveler Information. In the test corridor, drivers were provided with real-time information, both pre-trip and en route about incident conditions, expected delays, availability of transit and highway options, travel times, and availability of parking.
- Transit traveler information.
- Ramp metering
- HOT Lanes
- Arterial traffic signal coordination."[136]

[135] U.S. Department of Transportation. (2011). *Integrated Corridor Management.* Retrieved August 12, 2011, from: http://www.its.dot.gov/icms/about_icm.htm
[136] U.S. Department of Transportation. (2009). *Integrated Corridor Management (ICM) strategies that promote integration among freeways, arterials,and transit systems can help balance traffic flow and enhance corridor performance; simulationmodels indicate benefit-to-cost ratios for combined strategies*. Retrieved

The results focused on four key performance measures: mobility, reliability, safety, and emissions and fuel consumption. The following results, monetized benefits that are combinations of the performance measures, were reported:

- HOT lane and highway traveler information were consistently the most effective ICM investments. Converting and existing HOV lane to a HOT lane produced a benefit-to-cost ratio that ranged from 14:1 to 39:1.
- Highway traveler information produced a large benefit, especially in the case of unexpected events such as a major incident. In this case, the benefit-to-cost ratio ranged from 16:1 to 25:1.
- Transit traveler information produced less benefit than highway traveler information, but the impact remained positive with a benefit-to-cost ratio of 16:1.
- Local adaptive ramp metering produced a positive benefit-to-cost ratio that ranged from 6:1 to 12:1 on high demand days, but produced a negative benefit-to-cost on medium demand days.
- In high demand conditions, arterial signal coordination produced a benefit-to-cost ratio that ranged from 12:1 to 20:1. In medium-demand conditions, the benefit-to-cost ratio ranged from 4:1 to 13:1.
- Combining multiple ICM strategies produced a benefit-to-cost ratio that ranged from 7:1 to 25:1.[137]

3.4.3 Ramp Metering

The U.S. DOT Federal Highway Administration (FHWA) defines ramp metering as the "use of a traffic signal(s) deployed on a ramp to control the rate at which vehicles enter a freeway facility." By controlling the rate at which vehicles are allowed to enter a freeway, the flow of traffic onto the freeway facility becomes more consistent, smoothing the flow of traffic on the mainline and allowing more efficient use of existing freeway capacity. Ramp metering can be an effective tool to address congestion and safety concerns that occur at a specific point or along a stretch of freeway. It can also improve overall system performance by increasing average freeway throughput and travel speed, and decreasing travel delay. An additional benefit of ramp metering is that it can lead to a reduction in fuel consumption and vehicle emissions.[138]

Implementing a ramp metering application involves purchasing and installing a ramp meter assembly, signal displays, a controller, a cabinet, and detection and optimization equipment. Detection

December 29, 2010, from ITS Benefits Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ID/CCE9E850E04CFC9285257663006F8FFA?OpenDocument&Query=Home

[137] Ibid.

[138] US Department of Transportation Federal Highway Administration. (2006, January). *Questions and Answers*. Retrieved November 23, 2010, from Ramp Management & Control Handbook Project: http://www.ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/faqs/ramp_faqs.htm

equipment can include freeway sensors that assist in optimizing ramp meter signals based on real-time traffic conditions.[139]

Figure 3-6. Ramp Metering[140]

During 2002 and 2003, the Minneapolis-St. Paul DOT compared the use of a stratified metering strategy with no controls in place. Stratified metering maximizes freeway throughput but with an additional constraint to limit the waiting time on the ramps to a predetermined maximum. On a typical day, environmental benefits were apparent with a decrease in fuel consumption by more than three percent to six percent, and emissions reductions of three to eight percent. Different results were found on high demand days. Fuel consumption increased 13 percent and emissions increased by 2 to 3 percent. The negative impacts of stratified metering on high demand days are due to the increase of queued vehicles idling at the ramp meters, which increases fuel consumption and emissions.[141]

Another study conducted by the Minnesota DOT in 2001 evaluated the "impacts of shutting down an extensive ramp metering system on Minneapolis-St. Paul area freeways for a 6-week evaluation period." Four corridors that represent typical freeway configurations and conditions in the region were selected. Results showed:

- Without ramp metering, there was a net annual increase in emissions of 1,160 tons.
- Ramp metering decreases freeway travel times by 22 percent.
- Without ramp metering, there is a seven percent reduction in freeway speeds.

[139] US Department of Transportation: Research and Innovative Technology Administration. (n.d.). *Cost Elements: Ramp Meter*. Retrieved November 24, 2010, from ITS Costs Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/81EA80FC707801C785256F1F00618F40?OpenDocument&Query=Home

[140] US Department of Transportation (2011, January). *Freeway Management and Operations Handbook*. Retrieved August 2011: http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/images/fig8-13.jpg

[141] Xin, W., Hourdos, J., & Michalopoulos, P. G. (2006). Comprehensive Evaluation of a New Integrated Freeway Ramp. *Transportation Research Board 2006 Annual Meeting* (pp. 14, 25). Washington: Transportation Research Board.

- Without ramp metering, there is a decrease in fuel consumption of 5.5 million gallons; this is the "only category where ramp metering had a negative impact." This result occurred because the reduction in freeway speed in the meters-off condition actually created fuel savings.[142]

Ramp metering applications have demonstrated environmental benefits. A comparative analysis of emissions resulting from queued ramp vehicles versus emissions from vehicles traveling on the freeway mainline is needed to determine how to best optimize emissions reduction from ramp metering applications.

3.4.4 Speed Management

Speed management includes strategies focused on regulating vehicle speeds. These strategies may include reducing speed limits on freeways or more advanced strategies that change freeway speed limit based on real-time traffic conditions, and possibly energy consumption criteria, for smoother traffic flow. The latter are referred to as variable speed limit (VSL) systems.

Figure 3-7. Variable Speed Limits (VSL)[143]

In Finland, approximately 217 miles of roadway have been equipped with VSL signs. A study was completed in 2006 to estimate the benefits and costs of expanding the system, where "evaluation data collected from previous studies were projected onto the models which ranged in size from 2100 to

[142] U.S. Department of Transportation. (2001, February). *Net annual vehicle emissions increased by 1,160 tons and fuel consumption decreased by 5.5 million gallons when the ramp metering system on Minneapolis-St. Paul freeways was shut down*. Retrieved December 29, 2010, from ITS Benefits Database: http://www.itslessons.its.dot.gov/its/benecost.nsf/ID/8544E7BDD9BE1DDB8525733A006D539F?OpenDocument&Query=Home
[143] US Department of Transportation (2011, January). Freeway Management and Operations Handbook. Retrieved Agust 2011: http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/images/fig8-13.jpg

4300 km [1,304 to 2,672 miles]." Technologies used include VSL signs, combined information and warning systems, traffic monitoring stations, and CCTV cameras.[144]

A number of research initiatives have demonstrated environmental benefits derived from speed management applications. The Center for Transportation Research at the University of Texas at Austin, investigated the environmental benefits of a variable speed control strategy. A Monte Carlo simulation method, which uses random numbers and probability statistics to investigate problems, was developed to evaluate the effectiveness of VSL. It was found that by reducing the speed limit from 65 mi/h to 55 mi/h on "ozone action" days, the average daily total NO_x emissions in a 24-hour period could be reduced by approximately 17 percent on the selected freeway segment. The study noted that for optimal results "the flow and speed patterns of the selected roadway should be carefully investigated."[145]

Two European studies investigated whether reducing speed limits also reduces emissions levels. A study in Switzerland investigated the impacts on emissions when the maximum speed limit was changed from 120 km/h (75 mi/h) to 80 km/h (50 mi/h). The research found that if the speed limit was reduced, NO_x would be lowered by approximately four percent, but the peak ozone levels would remain relatively unchanged (less than one percent decrease). VOCs were also not significantly affected.

A second study in the Netherlands was conducted to examine whether a current speed limit reduction project that has demonstrated a decrease in nitrogen dioxide (NO_2) emissions could find additional emissions reductions if the speed limit was further reduced. The initial Overschie, Netherlands, project reduced the speed limit from 120 km/h (75 mi/h) to 100 km/h (62 mi/h). The study investigated whether further reducing the speed limit to 80 km/h (50 mi/h) would provide an additional reduction in NO_2 emissions during the study year (2002) and in 2010 and 2015. Using models, the study showed that an improvement in NO_2 emissions is possible, but that maximum benefits are found around the large cities of Amsterdam, Rotterdam, and Utrecht. NO_2 reductions averaged five percent.[146]

Graz, the second largest city in Austria, was the first European city to implement a reduction in speed limits from 50 km/h (31 mi/h) to 30 km/h (19 mi/h) for the entire city area.[147] During the initial two-year

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[144] Department of Transportation: Research and Innovative Technology Administration. (2006, March 25). *In Finland, the average implementation cost for a weather responsive roadside VSL system on a dual carriageway was estimated at 80,000€; average maintenance costs (including replacement costs) were estimated at 3,500 €/km/year*. Retrieved November 30, 2010, from ITS Costs Database: http://www.itscosts.its.dot.gov/its/benecost.nsf/0/5190F581A48EBF5C852573E900541637?OpenDocument&Query=Home

[145] Wang, Z., & Walton, C. M. (2006). *An Investigation on the Environmental Benefits of a Variable Speed Control Strategy.* Springfield: National Technical Information Service.

[146] Kalter, M. O., Van Beek, P., Stemerding, M., & Havermans, P. (2005). Reducing speed limits on highways: Dutch experiences and impact on air pollution, noise-level, traffic safety and traffic flow. *Proceedings of European Transport Conference 2005* (p. 11). Strasbourg: London Association for European Transport.

[147] CIVITAS Trendsetter. (2006). *Evaluation Report: Graz local activities (Trendsetter Report No. 2005:15).* Retrieved November 30, 2010, from CIVITAS: http://www.civitas-initiative.org/docs1/Graz_Evaluation_Reports_Local_Activities.pdf

trial, NO_x emissions were reduced by 25 percent.[148] Graz is also a part of the CIVITAS Initiative (CIty-VITAlity-Sustainability). The main goals of the CIVITAS initiative are to:

- Promote and implement sustainable, clean and energy efficient urban transportation measures;
- Implement integrated technology and policy measures in the field of energy and transportation; and
- Build a critical mass and markets for innovation.

Through the CIVITAS initiative, Graz expanded the number of streets that are part of the 30 km/h (19 mi/h) speed limit network. The city also implemented speed control devices to "inform drivers how fast they go without taking legal action against them in case they are too fast. It has proven a valuable and fairly simple awareness raising and speed reduction tool." These additional CIVITAS initiatives have led to a reduction of 268 tons of CO_2 emissions per year, 1 ton of NO_x emissions per year, and 1.78 million kWh of energy have been saved per year.[149]

3.4.5 Traffic Signal Control, Coordination, and Optimization

Adaptive signal control systems "coordinate control of traffic signals across a signal network, adjusting the lengths of signal phases based on prevailing traffic conditions."[150] These systems can include identification of individual vehicles and negotiated priority to minimize stops over the whole network, and therefore create smoother traffic flow.[151] Adaptive signal control can also include timing changes based on real-time measurement of pollutants and speed advice based on SPaT information.

Environmental benefits have been achieved through the implementation of adaptive signal control. In Lee's Summit, Missouri, located 20 miles southeast of Kansas City, the technology was implemented on a 2.5-mile arterial with 12 signals. The project reduced the average number of stops through the corridor, fuel consumption, and emissions for every period where travel times were reduced. Emissions both increased and decreased depending on whether or not the signal favored the direction of travel. When traveling in the direction favored by the signal, emissions decreased. When traveling in the direction not favored by the signal, emissions increased. The emissions changes ranged from an increase of 9 percent to a decrease of 50 percent:

- Fuel consumption: +4.5 percent to -21.4 percent
- HC: +6.2 percent to -42.6 percent

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[148] Washington State Department of Transportation. (2008, July 24). *Emissions and Speed Limit Literature Review.* Retrieved November 30, 2010, from Washington State Department of Transportation: http://www.wsdot.wa.gov/NR/rdonlyres/EE34C689-F53A-4EEF-95A6-370A9E74EE1F/0/emissionsandspeedlimitlitreview.pdf

[149] CIVITAS Trendsetter. (2006). *Evaluation Report: Graz local activities (Trendsetter Report No. 2005:15).* Retrieved November 30, 2010, from CIVITAS: http://www.civitas-initiative.org/docs1/Graz_Evaluation_Reports_Local_Activities.pdf

[150] U.S. Department of Transportation. (2009). *Applications Overview: Adaptive Signal Control.* Retrieved January 5, 2011, from Research and Innovative Technology Administration: http://www.itsoverview.its.dot.gov/Options.asp?System=AM&SubSystem=TC&Tech=Adaptive

[151] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.

- CO: +4.3 percent to -28.9 percent
- NO_x: +8.8 percent to -50.0 percent.[152]

Stockholm, Sweden, has also seen emissions reductions using adaptive signal control. The primary goal of the city's MATSIS project, which receives funding from both the City of Stockholm and the Swedish Environmental Protection Agency, is to "reduce the emissions of CO_2 through the use of coordinated traffic signaling."[153] Six areas of the city were selected for the project, and the initiative has led to a savings of an estimated 2,900 tons of CO_2 emissions per year. In addition to the emissions reductions, delays have been reduced up to 19 percent. The cost per kilogram of CO_2 saved is one of the lowest among all of Stockholm's environmental projects, and 70 percent of the positive effects of the project are expected to remain even if traffic increases in the project areas.[154]

Other benefits of adaptive signal control systems are summarized below:

- Adaptive signal control in Toronto, Canada, yielded emission reductions of three to six percent and fuel savings of four to seven percent.[155]
- In Tucson, Arizona, models indicated adaptive signal control in conjunction with transit signal priority (TSP) could decrease delay for travelers on the main street by 18.5 percent while decreasing delay for travelers on cross-streets by 28.4 percent.
- In Los Angeles, adaptive signal control systems improved travel time by 13 percent, decreased stops by 31 percent, and reduced delay by 21 percent.
- A University of Virginia simulation study found that adaptive signal control reduced delay by 18 to 20 percent when compared to fixed-time signal control.[156]

Traffic signal coordination and optimization involves the re-timing and synchronization of traffic signals to minimize vehicle delay and stops for smoother traffic flow.[157] The 2007 National Traffic Signal Report Card estimated that "updating signal timing costs less than $3,000 per intersection," can reduce emissions up to 22 percent, and has a high return on investment. For every dollar that is spent on traffic signal coordination, $40 or more is returned to the public in time and fuel savings. To support

[152] Hutton, J. M., Bokenkroger, C. D., & Meyer, M. M. (2010, March). *Evaluation of an Adaptive Traffic Signal System: Route 291 in Lee's Summit, Missouri.* Retrieved November 22, 2010, from Missouri Department of Transportation Innovation Library: http://library.modot.mo.gov/RDT/reports/Ri08026/or10020.pdf
[153] Kronborg, P., & Davidsson, F. (2009). Reduced CO2-emissions through co-ordinated signal control. In S. ITS, *Green and ITS: An Overview of Innovations for a Sustainable Transport System in Stockholm* (pp. 90-92). Sundbyberg: Alfaprint.
[154] Ibid.
[155] Greenough, & Kelman. (1999). ITS Technology Meeting Municipal Needs - The Toronto Experience. *6th World Congress Conference on ITS.* Toronto: ITS America.
[156] U.S. Department of Transportation. (2009). *Adaptive Signal Control*. Retrieved December29 2010, from ITS Benefits Database: www.itsbenefits.its.dot.gov/its/benecost.nsf/BenefitTerminators/AMS+Adaptive+Signal+Control
[157] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.

routine signal timing updates across the United States, "transportation agencies would need to spend an amount equivalent to less than 0.2 percent of the total national expenditure on highways."[158]

A number of traffic signal coordination projects in the United States have documented emissions savings. Some examples include:

- *Syracuse, New York:* The implementation of traffic signal coordination reduced emissions by 9 to 13 percent, reduced delays by 14 to19 percent, and increased the average speed by 7 to 17 percent.[159]
- *St. Augustine, Texas:* Traffic signal coordination in St. Augustine resulted in a savings of 26,000 gallons of fuel, reduced delays by 36 percent, and saved $1.1 million.[160]
- *Los Angeles, California:* Emissions reductions of 14 percent and a reduction of fuel by 13 percent were achieved by implementing traffic signal coordination.[161]
- *Oakland County, Michigan:* The County's traffic signal coordination project reduced CO by 1.7 to 2.5 percent, NO_x by 1.9 to 3.5 percent, and reduced fuel consumption by 2.7 to 4.2 percent.[162]

3.5 Freight Applications

Commercial Vehicle Operations (CVO) involve developing and adapting wireless technology for CVO and freight in order to enable communications among and between vehicles and infrastructure. With

[158] National Transportation Operations Coalition. (2007). *National Traffic Signal Report Card: Technical Report 2007.* Retrieved November 30, 2010, from Intitute of Transportation Engineers: http://www.ite.org/reportcard/technical_report%20final.pdf

[159] Department of Transportation: Research and Innovative Technology Administration. (2003, September). *By implementing coordinated signal timing on the arterial network in Syracuse, New York total fuel consumption was reduced by 9 to 13 percent, average fuel consumption declined by 7 to 14 percent, average vehicle emissions decreased by 9 to 13 percent*. Retrieved December 1, 2010, from ITS Costs Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ID/A9953A0DFDDA7B4885256E9B0052FB24?OpenDocument&Query=Home

[160] U.S. Department of Transportation: Research and Innovative Technology Administration. (2004, April). *Signal retiming projects in several U.S. and Canadian cities reduced fuel consumption by 2 to 9 percent.* Retrieved December 1, 2010, from ITS Costs Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ID/9399DC8274816F498525733A006D507F?OpenDocument&Query=Home

[161] U.S. Department of Transportation: Research and Innovative Technology Administration. (1994, June). *Fuel consumption fell by 13 percent and vehicle emissions were reduced by 14 percent due to a computerized signal control system in Los Angeles, California*. Retrieved December 1, 2010, from ITS Costs Database: http://www.itslessons.its.dot.gov/its/benecost.nsf/ID/C382FC6525B5B2CC8525733A006D4AC6?OpenDocument&Query=BApp

[162] U.S. Department of Transportation: Research and Innovative Technology Administration. (2004, November/December). *In Oakland County, Michigan retiming 640 traffic signals during a two-phase project resulted in Carbon monoxide reductions of 1.7 and 2.5 percent, Nitrogen oxide reductions of 1.9 and 3.5 percent, and hydrocarbon reductions of 2.7 and 4.2 percent*. Retrieved December 1, 2010, from ITS Benefits Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ID/CF3707B5930738FF8525733A006D546B?OpenDocument&Query=Home

respect to AERIS, the goal is to provide workable wireless technology solutions in CVO and freight that will engender decreases in environmental pollutants from medium- and heavy-duty vehicles. Considering this goal, researchers and others have begun to develop wireless technologies that modify truck operations or stimulate modifications in driver operations in order to decrease pollutants. Examples of these types of modifications include using GPS technologies to provide real-time feedback on routing, creating wireless communications between trucks in order to automate platooning between trucks, and using wireless communications to pre-authorize vehicles allowing them to bypass inspection stations.

3.5.1 Wireless Inspections

There are multiple United States transportation security and efficiency initiatives that impact the trucking industry. Included in these initiatives are programs that employ wireless technologies that communicate with trucks to complete remote inspections. In terms of security, conducting inspections remotely allows officials to devote resources to higher risk situations while at the same time monitoring a greater number of trucks on the roadway. In terms of the environment, the overriding benefit is that trucks will have to stop less frequently to receive inspections, therefore increasing the work performed and the cargo moved for the fuel expensed. Three national level programs are Smart Roadside, Trusted Truck®, and the Federal Motor Carrier Safety Administration's (FMCSA) wireless inspection program.

3.5.1.1 Smart Roadside

Smart Roadside is a U.S. DOT initiative to encourage cooperation between the various vehicles and transportation-associated organizations. The goals of Smart Roadside include improving safety and security, and enhancing freight mobility, driving efficiency, and vehicle operations efficiency. Smart Roadside is a sub-system of connected vehicle technology that has four main applications designed to enhance freight mobility and have a positive effect on the environment. These applications include: e-screening; truck size and weight; wireless roadside inspection (WRI); and truck parking. Although the principle goal of Smart Roadside is to increase freight vehicle safety, the real world benefits are those that reduce vehicle emissions by reducing the amount of time the trucks spend idling while waiting for inspection and allowing for advanced planning when deciding where to park the truck.[163]

3.5.1.2 Trusted Truck®

Trusted Truck® is a U.S. DOT support program financed by way of a research grant to the National Transportation Research Center, Inc. In Phase I of Trusted Truck®, the goal was to provide short wave communications that would allow government inspection stations to inspect truck braking systems in real-time across a wireless network. In Phase II, the goal expanded to include safety inspections for all the vehicles' systems. After the wireless inspection, the truck will receive either approval or disapproval to bypass the inspection station. Although the intent of the Trusted Truck® program is to enhance security in mobile transport, residual environmental benefits include more trucks being able to bypass weigh stations, and therefore reduced truck idling during waiting and inspection periods.

[163] Federal Motor Carrier Safety Administration, Federal Highway Administration, & and Research and Innovative Technology Administration. (2010). White Paper: Scope of the Smart Roadside Initiative.

3.5.1.3 FMSCA Telemetric Wiring

FMCSA similarly created a wireless inspection project with the goal of using on-board sensors and vehicle communication technologies to support vehicle inspections. The program also seeks to enhance "driver-fatigue warning systems, lane tracking systems, collision-avoidance systems, vehicle brake sensors, and tire pressure monitoring systems."[164] With regard to environmental benefits, increased frequency of tire pressure monitoring could increase fuel efficiency if this information is passed back to the driver, requiring him or her to remedy the situation. Driver fatigue can also lead to driver-related crashes. Monitoring driver fatigue and risky driver behavior and using the data to reduce the incidence of tired and risky drivers on the road may help prevent truck collisions.[165] Collisions can lead to increased emissions as a result of subsequent back-ups and congestion on the roadway.

A 2009 FMCSA work plan discusses a new truck-based research project that specifically investigates fuel consumption and operations management in addition to safety concerns. The test plan includes making vehicle design and manufacture improvements using onboard telematics technologies that monitor fuel consumption and "a driver's contribution to fuel consumption and safety." In addition to these onboard technologies, there will also be an easy-to-use, intuitive fleet management system using GPS and satellite technology. This system will provide tracking and monitoring services for the fleet vehicles. Usable outcomes of this fuel consumption monitoring project includes breakdowns of fuel transactions, fuel efficiency, miles per gallon, engine torque versus engine speed, vehicle speed, and hard breaking habits.[166]

In addition to national scale programs, there are also state level programs carrying out similar projects. Connecticut is one state that is a leader in wireless inspection technology. For example, the Connecticut Department of Motor Vehicles was the first state to deploy a statewide wireless communication system that provides real-time access to carrier safety information to freight vehicle inspectors. In 1996, Connecticut was one of 10 pilot states that participated in field testing for FMCSA's Commercial Vehicle Information Safety and Networks (CVISN) program. The pilot is focused on credentials administration, electronic screening (weigh station bypass), and safety information exchange .[167] More efficient electronic screening has the potential to further reduce freight environmental impacts.

[164] Hultin, J., Muschick, P., & Urbanik, T. (2008). Trusted Truck II (Phase A).
[165] Wireless Roadside Inspection Program for Commerical Motor Vehicles. (n.d.). *Federal Motor Carrier Safety Administration*. Retrieved August 9, 2010, from http://www.fmcsa.dot.gov/facts-research/art-technology-wireless-roadside-inspection-program.htm
[166] KLS Engineering. (2009). Testing and Evaluation of Truck-Based Fuel Monitoring and Operations Management Systems: Work Plan.
[167] Hultin, J., Muschick, P., & Urbanik, T. (2008). Trusted Truck II (Phase A).

3.5.2 Parking, Loading, and Delivery Management

Parking, loading, and delivery management enables the allocation of parking and loading/unloading areas to avoid unnecessary movements in urban areas. It can include infrastructure-to-vehicle communications for traveler information.[168]

The Cross-Town Improvement Program (C-TIP) in Kansas City, Missouri, is a good example of a loading and delivery management application that has the potential to reduce emissions. The Program's goal is to maximize loaded moves and to minimize unloaded moves. C-TIP assists freight carriers in meeting this goal by creating a collaborative environment that allows drivers and infrastructure to communicate, facilitate driving status updates, and provide real-time monitoring and feedback so that drivers and infrastructure can work together to maximize freight movement effectiveness and efficiency.[169]

There are five components to C-TIP:

1. Intermodal Move Exchange (IMEX) creates a set of offline business processes that would allow freight movement between rail and trucking to be more efficient, coordinate drop-offs, pick-ups, and deliveries to eliminate empty moves.
2. Wireless Drayage Updating (WDU) provides real-time updating on load assignments and pick-up and traffic information.
3. Chassis Utilization Tracking (CUT) manages the use of intermodal equipment, specifically to create a central pool of chassis equipment for all users.
4. Real-Time Traffic Monitoring (RTTM) expands on WDU to include roadway sensors, traffic probes, and third-party providers.
5. Dynamic Route Guidance (DRG) uses WDU and RTTM to provide turn-by-turn assistance to drivers that assists them in avoiding delays and missing intermodal exchanges.

In addition to improved roadway operations and conditions, and enhanced efficiency in freight movement, remedial benefits also include improved air quality and increased profitability. As a result of increased profitability, the trucking industry will be able to retire old fleet vehicles and purchase fewer, more environmentally friendly replacements, which will compound the benefits of the C-TIP freight efficiency program.[170]

The United Parcel Service (UPS) has employed several green delivery management initiatives. One such initiative, frequently referenced as the "right turns only" program, maps out individual driver delivery routes that reduce the number of left turns made. This helped UPS make substantial reductions in 2007. The shipper was able to eliminate 30 million miles from their streamlined delivery

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[168] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.
[169] Intermodal Freight Technology Working Group. (2009). Cross-Town Improvement Project Concept of Operations - 2009 Update. Retrieved June 15, 2010, from http://www.ctip-us.com/ctip_files/Concept%20of%20Operations%20Report%20-%20July%202009.pdf
[170] Ibid.

routes, reduce fuel consumption by 3 million gallons of gas, and reduce 32,000 MTCE over the course of the year.[171]

UPS has also deployed a telematics pilot in more than 20 US markets. Vehicle sensors are placed on all trucks involved in the pilot, and more than 200 vehicle-related elements are captured, including speed, revolutions per minute (RPMs), oil pressure, seatbelt use, and idling. The captured data are transferred through a 900 MHz radio to a centralized database at the end of the day. The initiative "uses advanced algorithms and proprietary firmware to analyze data captured by sensors in the company's ubiquitous brown delivery trucks to slash energy consumption, improve efficiency and customer service, and make its drivers safer on the roads." Data analysis has led to adjustments that reduced truck idling at two test sites by 24 minutes per driver per day, resulting in fuel savings of $188 per driver per year. With more than 90,000 drivers in the United States, the potential emissions and cost savings from this UPS initiative are significant.[172]

The University of California-Berkeley's Institute of Transportations Studies, in coordination with Caltrans, administers the California Partners for Advanced Transit and Highways (PATH). PATH conducted a literature review and subsequent truck driver survey with regard to commercial vehicle parking habits. One lesson learned from this endeavor is that there is a need for Parking Guidance Information (PGI) systems currently in use in Europe, the United Kingdom, and Japan. These systems provide real-time information for drivers concerning parking locations and availability, which assists drivers in finding an open location and prevents excess emission releases resulting from driving around looking for parking spaces. Specifically, these technologies can provide targeted, creditable messaging to drivers to help reduce vehicle travel with regard to searching for parking. Methods of relaying this information include on-board radio systems and electronic visual displays and the Internet.[173]

3.5.3 Platooning

With the exception of short dedicated truck lanes on steep inclines, designated truck lanes do not exist in the United States, despite discussion over integrating them into freeway systems. There are benefits of incorporating designated truck lanes into the freeway system. Within PATH research there is a focus on DSRC technologies for transportation agencies and industries to use in order to improve traffic. One DSRC technology on which PATH has focused is cooperative vehicle-highway automation systems (CVHAS), particularly with the purpose of platooning trucks. There is an emphasis for platooning technologies rather than automated steering due to the significant energy savings that

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[171] Davis, S. (2008, June 12). *Right Turn at the Right Time*. Retrieved December 8, 2010, from UPS: http://www.pressroom.ups.com/About+UPS/UPS+Leadership/Speeches/D.+Scott+Davis/Right+Turn+at+the+Right+Time

[172] United Parcel Service (UPS). (n.d.). *UPS Uses Telematics To Go - And Save - Green*. Retrieved December 8, 2010, from UPS Pressroom: http://www.pressroom.ups.com/Fact+Sheets/UPS+Uses+Telematics+To+Go+-+And+Save+-+Green

[173] Rodier, C., & Shaheen, S. (2007). Commercial Vehicle Parking In California: Exploratory Evaluation of the Problem and Possible Technology-Based Solutions. Retrieved July 19, 2010, from http://pubs.its.ucdavis.edu/publication_detail.php?id=1235

result from platooning.[174] According to research, platooning may yield a 10 to 20 percent fuel consumption savings.[175]

According to a PATH research report (2005), the necessary supporting attributes for developing automated truck platooning include those involving infrastructure, vehicles, wireless communications, and fault management systems. Truck automation coupled with platooning can decrease fuel usage and emissions and increase lane capacity.[176] Moreover, increased fuel economy and decreased operating costs will also favorably impact consumers.[177] In order to integrate automated technology into the freeway systems, however, creating designated truck lanes is essential because studies shows that automated truck driving should not be used when the truck is following a passenger vehicle. Researchers believe that both automated driving technologies and designated truck lanes are necessary and that implementing one will bring about the other. One legal complication with employing this system is that in some instances minimum distance requirements exist for spacing between trucks. In order to achieve fuel-reduction benefits, laws governing these regulations may have to change.[178]

One research effort underway through the California PATH Program has to do with platooning two or more trucks behind the lead truck. The benefits are increased fuel savings and increased roadway capacity. PATH has found that platooning reduces aerodynamic drag, resulting in the fuel and carbon emissions savings between 10 and 20 percent for trucks cruising at highway speeds. PATH has "demonstrated the drag savings in scale-model wind-tunnel tests of four trucks and full-scale track tests of two trucks." With increased benefits comes increased complications and risk. For example, the enhanced CVHAS and V2V technology must support lane changing and trucks attaching and detaching themselves to and from the platoon.[179]

An example of a platooning application for freight is the electronic tow bar. Electronic tow bars are an application where the lead vehicle is driven manually and a following vehicle is driven automatically by a vehicle controller that maintains a set distance between the two vehicles. The concept "is similar to ACC except that the gap between the lead and trailing vehicles is much smaller to take advantage of the aerodynamic drag reduction from the slipstream effect. Because of this small separation distance,

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[174] Shladover, S., Lu, X., Song, B., Dickey, S., Nowakowski, C., Howell, A., et al. (2005). Demonstration of Automated Heavy-Duty Vehicles. Retrieved July 19, 2010, from http://www.path.berkeley.edu/PATH/Publications/PDF/PRR/2005/PRR-2005-23.pdf

[175] Shladover, S., Lu, X., & Cody, D. (2009). Development and Evaluation of Selected Mobility Applications for VII: Concept of Operations. Retrieved July 19, 2010, from http://www.path.berkeley.edu/PATH/Publications/PDF/PWP/2009/PWP-2009-03.pdf

[176] Shladover, S. (2009). Deployment Path Analysis for Cooperative ITS Systems.

[177] Shladover, S., Lu, X., Song, B., Dickey, S., Nowakowski, C., Howell, A., et al. (2005). Demonstration of Automated Heavy-Duty Vehicles. Retrieved July 19, 2010, from http://www.path.berkeley.edu/PATH/Publications/PDF/PRR/2005/PRR-2005-23.pdf

[178] Shladover, S. (2009). Deployment Path Analysis for Cooperative ITS Systems.

[179] Shladover, S., Lu, X., & Cody, D. (2009). Development and Evaluation of Selected Mobility Applications for VII: Concept of Operations. Retrieved July 19, 2010, from http://www.path.berkeley.edu/PATH/Publications/PDF/PWP/2009/PWP-2009-03.pdf

typically one-half to one truck length, precise control must be maintained by the trailing vehicle to prevent the vehicles from contacting if the lead vehicle suddenly brakes."[180]

The following vehicle is equipped with radar, laser, or optical sensors to measure the separation distance, and V2V communications are used to share information on the lead vehicle's speed and acceleration to allow the following vehicle time to respond to any sudden acceleration or stops by the lead vehicle. The "electronic tow bar would be most applicable to line-haul trucks using the interstate system. Although it is possible to extend the concept to more than two vehicles, it is unlikely that this would be allowed, with the possible exception of truck-only lanes." Electronic tow bars are not commercially available at this time.[181]

A 2010 report by National Research Council's Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles cited two experiments where the environmental benefits of electronic tow bars were documented.

- Bonnet and Fritz (2000) conducted experiments on two heavy-duty semitrailer Mercedes-Benz trucks of type ACTROS 1853 LS, both having cab-over-engine design. The lead truck was 32,000 lb. and the trail truck was 62,000 lb. For the trail truck with the separation distance varied between 8 and 16 m, the fuel consumption reduction ranged from 15 to 21 percent at 80 km/hour and from 10 to 17 percent at 60 km/hour when compared with the truck driving in isolation. For the lead truck, the fuel consumption reduction was between 5 and 10 percent at 80 km/hour and between 3 and 7 percent at 60 km/hour.
- Browand et al., (2004) report on experiments conducted on two Freightliner 2001 Century Class trucks with 53-foot van trailers. The tractors were engine-forward design. One vehicle was 32,000 lb. and the other was 64,000 lb. At a constant speed of 55 mph, the measured fuel saving at a spacing of 10 m were 10 percent and 6 percent, respectively, for the trail and lead truck. In the spacing range of 3 to 10 m, fuel consumption savings were in the range 10 to 12 percent for the trail truck and 5 to 10 percent for the lead truck, with the larger values of savings occurring at the shorter spacing. [182]

In summary, electronic tow bar testing has demonstrated the ability for the application to reduce fuel consumption by 10 to 21 percent for the following truck, and 3 to 10 percent for the lead truck. Larger reductions are achieved when the spacing between the vehicles is shortened. Savings in fuel consumption can lead to a reduction in emissions, as well.

3.5.4 Eco-Driving for Freight

A driver's behavior and driving patterns in heavy-duty vehicles significantly impact both fuel consumption and emissions. Particularly with heavy-duty vehicles, acceleration and deceleration can significantly increase energy consumption and emissions. For example, if a truck moves at 50 mi/h, decelerates to a stop and then resumes prior speed, the driver increased both the vehicle's fuel consumption by one liter and driving time by 30 seconds. Therefore, by maintaining a constant speed

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[180] The Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles. (2010). *Technologies anApproaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles.* Washington, DC: The National Academies Press.
[181] Ibid.
[182] Ibid.

to the greatest degree possible will significantly improve fuel economy.[183] One solution to this problem is to encourage eco-driving by way of creating an incentive program to entice drivers to reduce their fuel consumption through improved driving behavior.[184] Wiklunds, a Swedish haulage company, strongly promotes eco-driving both through training programs and through feedback with data gathered from on-board systems. To further promote eco-driving, Wiklunds gives individual salary bonuses to those drivers who show high reductions in fuel consumption.[185]

Scania Group, a truck retailer in Sweden, developed an information technology (IT)-based system called Scania Driver Support. This system gives truck drivers real-time feedback and tips to help improve their driving with the goal of improving truck fuel economy. Using this performance monitoring system, drivers were able to reduce their fuel consumption 5 to 20 percent – even experienced drivers significantly decreased consumption. The system works by monitoring various systems throughout the truck and providing feedback to the driver based on system performance. This type of feedback helps the driver maintain awareness while driving, which also improves safety in addition to the desired fuel economy benefits. This monitoring system couples with the driver training that Scania employees receive initially, serving as reinforcement.[186] In Japan, the government is also promoting processes and technologies similar to the Scania processes, including a national campaign that subsidizes the Eco-Driving Management System that, like Scania, combines on-board equipment and training for freight operators.[187]

The City of Göteborg, Sweden, instituted a citywide incentive program for trucks to promote eco-driving. This program resulted from the large numbers of lightly loaded trucks crowding the city. The city constructed designated lanes and loading spots that drivers can use to decrease travel and loading time. To use them, however, the Transport Office requires the drivers to report their load factor via data transmitted from a digital pen and digital form by general packet radio service (GPRS).[188]

FREILOT is an urban freight energy efficiency pilot that is supported by the European Commission and aims to demonstrate through four linked pilot projects that freight fuel consumption in urban areas can be reduced up to 25%. The pilots focus on achieving fuel reductions through targeted eco-driving, energy efficient intersection control, adaptive speed acceleration controls, and real-time loading/delivery space booking. This project encourages truck fleets to use eco-driving techniques such as acceleration and speed limiters and eco-driving support. Trucks that have these technologies receive priority at certain intersections, roads, or during certain times of the day. The ultimate project goal is to make these technologies widespread in Europe and integrate them into mainstream urban

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[183] Sauna-aho, P., & Sauna-aho, J. (2007). Driving Habits and Transport Telematics Applications. *14th ITS World Conference*.

[184] Liimatainen, H. (2008). Fair and Intelligent Ecodriving Incentive System for HDV Drivers. *15th ITS World Conference*.

[185] "Eco-driving" Cuts Fuel Consumption. (n.d.). *Advantage Environment*. Retrieved August 10, 2010, from http://advantage-environment.com/transporter/%E2%80%9Ceco-driving%E2%80%9D-cuts-fuel-consumption

[186] Scania Group. (2009, September 17). Scania Takes Eco-driving to a New Level with its Latest Digital Performance Coaching Technology. *Scania Group*. Retrieved August 10, 2010, from http://www.scania.com/media/pressreleases/n09025en.aspx

[187] Integrated Approach in Road Transport. (n.d.). *JAMA - Japan Automobile Manufacturers Association, Inc*. Retrieved August 10, 2010, from http://www.jama-english.jp/europe/news/2010/no_1/art2.html

[188] Rydin, R. (2007). Incentive Schemes for a Cleaner Urban Environment: - The Case of the City of Goteborg. *14th ITS World Congress*.

traffic control systems. Unlike the Scania project, which targets driver behavior and provides incentive to individual employees, this project targets the fleet owners and, consequently, their suppliers. Thus, the incentive for the fleet owners is reduced costs; however, the project is also addressing issues of "driver acceptance, business models, cost-benefit investigation and regulatory aspects."[189]

3.6 Transit Applications

Transit's role in reducing GHG emissions is the focus of much on-going research in the transportation industry. Research in the area of ITS for transit applications shows that advanced technologies that enable smart vehicles, smart travelers, and smart infrastructure (intermodal systems) have the potential to improve air quality and reduce energy consumption in the transportation sector. This section highlights the state of the practice where ITS is used in transit applications.

3.6.1 Automated Vehicle Locations (AVL) and Computer-Aided Dispatch (CAD)

Technologies such as AVL and CAD systems not only improve fleet operations, which may in turn reduce VMT and fuel consumption, but also help to make transit a more viable alternative for travel through improved reliability and vehicle operations.[190] AVL systems also allow transit operators to better manage incidents and accidents that may delay transit vehicles and waste fuel. Operators may take a proactive response to incidents and re-route buses around major traffic problems, thereby saving fuel and enhancing the fuel efficiency of the overall fleet.[191]

3.6.2 Demand Responsive Dispatching and Scheduling Systems

Demand responsive dispatching and scheduling systems, enabled through ITS, allow efficient operations of flexible vehicle routing and demand-responsive transit services. Automating the functions of scheduling, dispatching, accounting, and billing improves the overall efficiency of transit services, allowing reductions in vehicle emissions of up to a magnitude of 6.5 times on a per passenger-mile basis.[192] Furthermore, these services may indirectly induce travelers to use transit or paratransit services rather than single-occupancy vehicles, yielding additional environmental savings.

3.6.3 Traveler Information Systems

Real-time information systems help travelers choose the best routes and departure times based on roadway conditions and transit routes, schedules, fares, and vehicle arrival information.[193] Innovative

[189] FREILOT Pilot to Improve Energy Efficiency of Urban Freight Transport. (2009). *ertico.com*. Retrieved July 19, 2010, from http://www.ertico.com/en/news/ertico_newsroom/freilot.htm
[190] Gomez, A., Zhao, F., and Shen, L.D. (1998). Benefits of Transit AVL and Transit AVL Implementation in the U.S. Presented at the 77th Annual Meeting of the Transportation Research Board, Washington, DC.
[191] Turnball, K. F. (1993). Evaluation of Automatic Vehicle Location Systems in Public Transit. Research Report No. TX/SWUTC-93/3006-IF.
[192] Jolibois, S. C., and Kanafani, A. (1994). An Assessment of IVHS-APTS Technology Impacts on Energy Consumption and Vehicle Emissions of Transit Bus Fleets. California PATH Research Report No. UCB-ITS-PRR-94-19.
[193] Apogee and Hagler Bailty. (1998). Intelligent Transportation Systems: Real World Benefits. Publication FHWA-JPO-98-018. FHWA, U.S. Department of Transportation.

ITS technologies such as these, designed to improve public information about public transit alternatives, will induce a modal shift away from alternatives that create more pollution and consume more fuel per person trip and towards a more environmentally sustainable option.[194] Displaying transit related messages on Changeable Message Signs (CMS) that compares freeway driving time with station-to-station transit trip time and next train schedule will encourage commuters to use trains during rush hour. In fact, the California DOT (Caltrans) is doing just this in the Bay Area. A study conducted by Caltrain, the commuter rail system that provides service between San Francisco and San Mateo and Santa Clara counties, analyzed peak-hour freeway driving time and train trip time for three locations where CMS signs displayed transit information. The study showed that train trip time is significantly less during the morning and afternoon peak hours compared to driving on the freeways. The project team is assessing the effectiveness of the transit signs on commuters' behavior to determine the percentage of commuters who have changed or are willing to change travel modes from car to transit, but this work is not yet complete. Additionally, the researchers plan to incorporate real-time train travel information into the system as well as parking availability information.[195]

3.6.4 Transit Signal Priority

The benefits, impacts, and technical performance of a public transit telematics system were investigated in Helsinki, Finland. The system provided signal priorities to transit vehicles behind schedule at signalized intersections. Under these conditions, a vehicle simulation of a Euro III emissions-standard-compliant city bus resulted in a decrease in fuel consumption by 3.6 percent, and a decrease in all forms of exhaust emissions including: NO_x by 4.9 percent, CO by 1.8 percent, HC by 1.2 percent, and PM by 1.0 percent.[196]

Two studies, one in Southampton and the other in Eastleigh, England, conducted in 1999 by researchers at the Transport Research Laboratory found reductions in bus fuel consumption and emissions with TSP implementation. The results of the Southampton study show fuel consumption reductions by 13 percent and lowered emissions between 13 and 25 percent, while fuel consumption reductions of 19 percent with reduced bus emissions between 15 to 30 percent where shown in Eastleigh. In each of these studies, non-transit vehicles showed an increase in both fuel consumption and emissions. The Southampton study showed an increase in fuel consumption by non-transit vehicles by approximately 6 percent with up to 9 percent increased emissions. Similarly, the results of the Eastleigh study showed a 5 percent increase in fuel consumption and an increase of up to 11 percent in emissions by non-transit vehicles. These results reflect the trade-offs in benefits often encountered between transit vehicles and non-transit vehicles in TSP implementation strategies.[197,198] Another study, *Evaluation of Potential Transit Signal Priority Benefits Along a Fixed-Time Signalized*

[194] Martinez, M. J. (2009). Calculation of Benefits of Advanced Integrated Rail Service: Application of Intelligent Transportation Systems to the Developing City of Lima, Peru. Transportation Research Record: Journal of the Transportation Research Board, No. 2112, Transportation Research Board of the National Academies, Washington, D.C., pp. 26-33.

[195] Mortazavi, A., Pan, X., McDonald, T., Jin, E., Odioso, M. (2009). Commuter Travel Time Information System: Displaying Transit Messages on Changeable Message Signs. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, DC.

[196] Lehtonen, M. and Kulmala, R. (2002). Benefits of Pilot Implementation of Public Transport Signal Priorities and Real-Time Passenger Information. Transportation Research Record, Vol. 1799. No. 02-2357.

[197] Transport Research Laboratory. (1999). Monitoring and Evaluation of a Public Transport Priority Scheme in Southampton. Publication Report No. 413, University of Southampton and University of Portsmouth.

[198] Ibid.

Arterial, shows the impact of TSP implementation on the overall traffic stream, representing all motor vehicles that occupy the roadway. In this case, the researchers showed that the net impacts of TSP implemented along an arterial could decrease HC and CO emissions for all traffic by 0.3 percent, and 0.6 percent respectively, while also increasing fuel consumption and NO_x emissions by 0.3 percent, and 0.18 percent, respectively.[199] Further research is necessary to identify the benefits and tradeoffs of TSP, including the benefits and tradeoffs achieved when combined with other connected vehicle applications.

3.6.5 Fuel Consumption and Emissions Reduction Strategies

3.6.5.1 Use of Alternative Fuels

Many of the environmental benefits realized through public transportation often begin with the selection and use of alternative fuels and vehicle types in transit fleets. The current state-of-the-practice provides guidance on the evaluation, selection, and implementation of alternative fuel choices for transit bus operations.[200] The literature explores the use of compressed and liquefied natural gases, fuel cells, biodiesel fuel, methanol-fueled engines, diesel-electric, gasoline-electric, and battery-electric hybrid buses, as well as others. [201,202,203] Information related to these technologies is made available for transit agencies in support of green choices during the fleet procurement and maintenance processes. Further, a report published by the Federal Transit Administration (FTA) presents the relative emissions and efficiency impacts benefits of the various technologies for comparison. The report concludes that diesel-electric buses appear to offer the best overall environmental benefits and that it is the only technology to result in a reduction in fossil fuel consumption.[204]

3.6.5.1 Operations Management

Environmentally harmful impacts of the transportation sector may be alleviated through improved transit operations management. The following topics present the current state-of-the-practice research in operations management.

Green Vehicle Allocation

A 2009 study by the University of Rome (Italy), *Transit Network Design with Allocation of Green Vehicles: A Genetic Algorithm Approach*, provides guidance to transit agencies on how they may

[199]Dion, F., Rahka, H., Zhang, Y. (2002). Evaluation of Potential Transit Signal Priority Benefits Along a Fixed-Time Signalized Arterial. Presented at the 81th Annual Meeting of the Transportation Research Board, Washington, DC.
[200]Schiavone, J. J. (2007). TCRP Synthesis 72: Use of Biodiesel in a Transit Fleet. Transportation Research Board, Washington, D.C.
[201]Ibid.
[202]National Renewable Energy Laboratory (NREL). (2008). Hydrogen and Fuel Cell Transit Bus Evaluations. Technical Report Publication NREL/TP-560-42781-1.
[203] Center for Transportation and the Environment (CTE). (2009). A Report on Worldwide Hydrogen Bus Demonstrations, 2002-2007. Publication FTA-GA-04-7001-2009.01. FTA, U.S. Department of Transportation.
[204]Wayne, S., Sandoval, J. A. (2007). Environmental Benefits of Alternative Fuels and Advanced Technology in Transit. USDOT FTA-WV-26-7003-07.2

allocate green vehicles within their fleet. The authors concluded that transit agencies are introducing low emission vehicles into their fleets, but there are a limited number of low emission vehicles available for acquisition, which limits the number of green transit lines created. To address this issue, the report prescribes a two-part algorithm procedure designed to optimize the allocation of energy-efficient vehicles, and therefore minimize the negative environmental externalities associated with higher polluting vehicles that remain in the fleet.[205]

Automated Driving

Another study, *Operational Requirements of Advanced Public Transport Services*, evaluated the benefits of advanced driver assistance systems and automated driving lanes. The researchers assert that by platooning transit vehicles, fuel consumption and pollution may be reduced by smoothing traffic flow and improved aerodynamics. Researchers at California PATH also demonstrated the automation of heavy-duty vehicles including transit buses. Among other benefits demonstrated, the team showed that bus automation can offer greater vehicle and passenger lane-capacity by enabling buses to operate at shorter headways than under manual control.[206] Vehicle platooning operations, such as this can, in turn, reduce fuel consumption and emissions for buses due to reductions in aerodynamic drag.[207]

Excessive Idling Mitigation

Researchers at the University of Illinois at Chicago examined the application of idling-reduction technologies for Chicago Transit Authority transit buses. The study found that by borrowing idling-reduction devices in use in the freight trucking industry, such as auxiliary power units, battery powered AC/diesel-fired heaters, automatic shutdown/start-up devices, and using direct power connection during general cleaning, transit agencies can not only reduce costs, but also reduce fuel consumption and improve air quality. The researchers estimated that by implementing such strategies, the Chicago Transit Authority could eliminate “120 tons of NO_x, 3 tons of PM, and 5,887 tons of CO_2 annually. This amount of CO_2 is equivalent to the annual greenhouse gas emissions from almost 1,000 passenger vehicles.”[208]

3.6.6 Land-Use Control

Effective strategies for increasing the use of public transportation and lowering the GHG emissions of the transportation sector include reforming land-use practices using dedicated lanes and through the provision of exclusive rights-of-way for transit systems, as an example. The following section provides the current state-of-the-practice in this regard.

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[205] Beltran, B., Carrese, S., Cipriani, E., Petrelli, M. (2009). Transit Network Design with Allocation of Green Vehicles: A Genetic Algorithm Approach. Transportation Research Part C. Vol. 17, pp. 475-483.

[206] Marques, A., Serrano, M., Calatayud, A., Zambrano, A. (2009). Operational Requirements of Advanced Public Transport Services. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, DC.

[207] Shladover, S. E., Lu, X., Song, B., Dickey, S., Nowakowski, C., Howell, A., Bu, F., Marco, D., Tan, H., Nelson, D. (2005). Demonstration of Heavy-Duty Vehicles. Publication UCB-ITS-PRR-2005-23, California PATH Research Report.

[208] Ziring, E. and Sriraj, P. S. (2010). Mitigating Excessive Idling of Transit Buses. Presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.

3.6.6.1 Dedicated Lanes and Bus Rapid Transit (BRT)

Many cities around the world have adopted high capacity and high performance bus-based transit systems, commonly known as BRT systems.[209] Besides improving the quality of public transportation in these cities, BRT systems have the potential to reduce GHG emissions and other harmful pollutants. A University of Sao Paulo, Brazil, study shows that the potential of BRT implementation on modal shift has a significant influence on emissions, as does the work by researchers at Northwestern University. In both cases, the researchers assert that by attracting car users to buses, volumes of autos can be reduced on the roadways, thereby limiting the negative impacts on emissions. They warn, however, that significant changes in modal shift, and therefore also the improvement of environmental conditions, may only be realized with large-scale, integrated public transport systems. Furthermore, the University of Sao Paulo, Brazil, researchers identify the relative impact of different variables related to BRT systems on emissions. They considered a set of scenarios that introduce different elements of BRT system design and technology as well as policy decisions typical in BRT implementation in Sao Paulo, Brazil. Overall, the results show a general trend of reduced emissions with improved bus operations (i.e. improved stops and traffic control), reduced auto speeds (i.e. consequence of bus priority), modal shift, car fleet renewal, inspection and maintenance programs, and by fueling all buses with ultra-low sulfur diesel.[210,211]

Furthermore, the research results of an FTA study assert that BRT elements such as TSP, queue-jumper lanes, enhanced station design, dedicated lanes, real-time bus arrival information, electronic fare payment, and low-floor vehicle design can lead to transit travel time savings by as much as 25 percent in the U.S., and between 20 and 120 percent in international BRT systems. While this research does not directly assess the environmental benefits afforded through BRT implementation, it does address the indirect benefits, such as increased ridership and reduced personal VMT. The researchers assert that these benefits are associated with providing better transit service, and can ultimately lead to reduced GHG emissions and environmental pollutants.[212]

Research conducted by the Institute for Transportation and Development Policy in 2010, however, directly assesses the GHG impacts of BRT systems. Specifically, the researchers developed a methodology for estimating CO_2 impacts for BRT systems in Bogotá, Columbia; Mexico City, Mexico; and Jakarta, Indonesia. Their work is primarily focused on factors that reduce GHG emissions through changes in modal structure. By comparing the CO_2 impact methodologies used in each city, the authors conclude that it is possible to develop an estimate of the CO_2 benefits of a BRT project

[209]Diaz, R. B. and Hinebaugh, D. (2009). Characteristics of Bus Rapid Transit for Decision-Making. Publication FTA-FL-26-7109.2009.1.FTA, U.S. Department of Transportation.
[210] Castro, C. F. and Strambi, O. (2010). Assessing the Net Effect on Emissions of the Implementation of a BRT System in Sao Paulo, Brazil: A Case Study and some Hypothetical Scenarios. Presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.
[211] Chen, R. B., and Mahamassani, H. S. (2009). Back to Basics: Demand, Supply and Emissions Analysis for Urban Mobility Interventions. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington, DC.
[212]Baltes, M. B., and Hardy, M., H. (2007). Bus Rapid Transit Sketch Planning: The Process of Building a Better Bus System for Miami-Dade County. Presented at the 86th Annual Meeting of the Transportation Research Board, Washington, DC.

based on the projected modal shift, the load factor (passenger kilometers/bus kilometers), and the projected speed improvement of BRT buses.[213]

Researchers at Beijing Jiaotong University and Texas Southern University, Houston, have examined the impact of public transit priority on emissions in Beijing, China. Specifically, the researchers show that NO_x, CO, and PM emissions on road segments with exclusive bus lanes are approximately 10 percent less compared to normal traffic on road segments without these dedicated lanes, and 20 percent less in HC emissions. They also find that the reduction ratio for each pollutant reaches about 10 percent when comparing conventional bus routes (operating in mixed traffic) to BRT systems operating in dedicated lanes.[214]

3.6.7 Data Collection and Evaluation

3.6.7.1 Transit Vehicles Used as Field Probes

Using available ITS technologies, researchers at Portland State University (Oregon) used transit buses as probe vehicles to assess the performance of arterials. Specifically, the researchers used Portland's TriMet buses equipped with a bus dispatch system (BDS) including AVL, GPS, automatic passengers counters (APC), wireless communications, and stop-level data archiving capabilities to collect speed and travel time data. In order to assess the extent to which bus travel characteristics are related to those of general traffic, the team collected data with GPS instrumented passenger vehicles for comparison. The study reports that passenger vehicle speeds and travel times are 1.7 times greater than for buses. The researchers have shown that the fusion of location-based data (transit data from BDS) and time-based data (passenger vehicle GPS) reveal that actual arterial traffic conditions can be described using transit vehicle AVL information.[215]

A project implemented in King County with Washington State DOT and University of Washington collaboration demonstrates the viability of using an AVL-equipped fleet of transit vehicles as a regional traffic surveillance system suitable for both traffic management and the provision of traveler information. Researchers collected AVL data from buses serving as probe vehicles, converted the data into roadway speed information, and created color-coded congestions maps that reflect real-time traffic information available for use by the traffic management center as well as travelers in the form of online applications that display a map-based view of real-time probe data.[216]

Another study that used transit buses as probes is the Orange County Transit Authority (OCTA) probe project – a joint effort of the OCTA, California DOT, and the cities of Anaheim and Santa Ana. The probe project equipped a fleet of buses with GPS-based tracking equipment for the purpose of bus

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[213] Hook, W., Kost, C., Navarro, U., Replogle, M., Baranda, B. (2010). CO2 Reduction Benefits of Bus Rapid Transit Systems: Learning from Bogota, Mexico City, and Jakarta. Presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.
[214] Hao, Y., Yu, L., Song, G., Xu, Y., Wang, H. (2010). Analysis of Driving Behavior and Emission Characteristics for Diesel Transit Buses Using PEMS' Measurements. Presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.
[215] Tantiyanugulchai, S., and Bertini, R., L. (2003). Arterial Performance Measurement Using Transit Buses as Probe Vehicles. IEEE Proceedings on Intelligent Transportation Systems. Vol. 1, pp. 102-107.
[216] Daily, D. J., and Cathey, F. W. (2005). AVL-Equipped Vehicles as Speed Probes. Publication WA-RD 617.1, U.S .Department of Transportation Federal Highway Administration.

schedule adherence, fleet management, traffic congestion monitoring, and transit data dissemination to patrons. The transit probe system consists of OBUs that determine bus location through differential GPS, base-station software used to track and store data, and a wireless communication system for both short and long range communications between buses and base stations. Unfortunately, the study objectives were never met due to several factors including budgetary constraints and priority changes among the agencies involved, so a complete assessment of the probe project is not available.[217,218]

3.6.7.2 On-Board Emissions Measurement

There is considerable research underway on sensors that can detect pollutants in vehicle exhaust. A scan of the literature shows that direct vehicle emissions measurements are either performed in a laboratory with an engine dynamometer or occur during in-use operation with portable emissions measurement systems (PEMS). Researchers at Beijing Jiaotong University and Texas Southern University collected real-world emissions data from diesel buses using PEMS, and driving activity data from GPS. The driving activity data are used to identify Vehicle Specific Power (VSP) distributions for buses and combined with established emissions rates for VSP-bins to analyze emissions characteristics of buses. The researchers performed an analysis of driving behavior and resultant emissions characteristics for diesel buses. Their results offer spatial and temporal emission rate data for diesel-powered buses, providing further evidence of the environmental benefits afforded with transit priority strategies, such as BRT and dedicated lanes.[219]

From a spatial perspective, emissions factors on freeways are the lowest, and the emissions factors on minor arterials are the highest. Emission factors are also higher at bus stations, where NO_x, HC, CO, and PM are 1.64, 3.33, 2.65, and 1.73 times higher than on regular road segments, respectively. The researchers suggest that improving driving conditions at bus stations is important to reducing emissions from diesel transit buses. From a temporal perspective, the emissions factors are higher during the morning and evening peak hours. Notably, NOx, HC, CO, and PM emissions factors are 1.18, 1.23, 1.11, and 1.16 higher during peak hours than off-peak hours, respectively. The researchers suggest that reducing peak hours in Beijing can also reduce emissions from diesel transit buses. It was found that average travel speeds for exclusive bus lanes is approximately 11 percent higher than normal travel lanes, which decreases emissions by approximately 10 percent. BRT routes can also reduce emissions by approximately 10 percent.[220]

Researchers at the University of California, Riverside, and the International Sustainable Systems Research Center, a California-based non-profit that works with developing countries achieve environmentally sustainable development, compared results from PEMS to emissions rates obtained in standard laboratory equipment to assess the potential value of using PEMS to determine real-world vehicle emissions impacts of transportation projects. Agreement between PEMS and laboratory

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[217] Hall, R. W. (1997). Orange County Transit Probe Evaluation: Phase I Institutional Findings. Publication UCB-ITS-PWP-97-12, California PATH Working Paper.
[218] Hall, R. W., Vyas, N., Shyani, C., Sabnani, V., Khetani, S. (1999). Evaluation of OCTA Transit Probe System. Publication UCB-ITS-PRR-99-39, California PATH Research Report.
[219] Hao, Y., Yu, L., Song, G., Xu, Y., Wang, H. (2010). Analysis of Driving Behavior and Emission Characteristics for Diesel Transit Buses Using PEMS' Measurements. Presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.
[220] Ibid.

modal systems varied somewhat depending on the pollutant, but overall PEMS were shown to have a quick and precise response to most pollutants for most driving cycles. The researchers assert that PEMS are reliable for emissions measurement in both gasoline and diesel powered vehicles.[221]

Finally, research conducted by North Carolina State University, Raleigh, assessed the linkage between vehicle emissions models and transportation models. The research evaluates emissions during a trip that depends on vehicle dynamics. The researchers contend that vehicle dynamics influence the instantaneous vehicle engine load, as reflected by the speed profile. Ultimately, the study concluded that average emissions rates for diesel-powered transit buses tend to increase with average speed.[222]

3.7 Other Applications

3.7.1 Bicycles Used as Field Probes

Bicycles can be retrofitted in order to use them as field probes. Wheel hub applications collect data in real time, including real-time traffic operations monitoring, incident detection, route guidance applications, and emissions data. Various components are housed in the hub, including: a motor; three-speed internal hub gear; batteries; a torque sensor; GPRS; and a sensor kit that monitors CO_2, NO_x, noise, humidity, and temperature. The hub can also be Bluetooth-enabled in order to provide wireless connectivity.[223]

The "Copenhagen Wheel," under development by the Massachusetts Institute for Technology's SENSEable City Lab for the City of Copenhagen, with support from the Italian Ministry for the Environment and Ducati Energia, is one example of an application that allows a bicycle to be used as a field probe. At a cost of approximately $600 per wheel, the Copenhagen Wheel converts a conventional bicycle into a hybrid electric bicycle. The purpose of the conversion is two-fold: 1) Energy is captured through cycling and regenerative braking to give the rider extra power when needed; and 2) The sensor kit collects data to map pollution, traffic congestion, and road conditions in real time. A Bluetooth enabled mobile device, such as a smartphone, can be installed on the handlebars to synchronize with the Bluetooth module in the wheel hub. Through the phone, the user can lock and unlock the bike, change gears, select the motor assist option, and view the collected real-time data.[224]

Data collected, such as speed, direction, distance travelled, air pollution, noise, and weather, is owned by the user and can be shared anonymously. When a large number of users share their data (also known as "crowd sourcing"), it is possible to analyze the collective data and identify environmental and transportation trends across a city. Data at this fine scale enables city officials to make fact-based

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[221] Lui, H, Barth, M., Scora, G., Davis, N., Lents, J. (2009). Using Portable Emissions Measurement Systems for Transportation Emissions Studies: Comparison with Laboratory Methods. Presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.
[222] Zhai, H., Frey, C., Rouphail, N. M. (2006). Speed- and Facility Specific Emissions Estimates for Transit Buses Based in Measured Speed Profiles. Proceedings in the Annual Meeting of the Air & Waste Management Association, New Orleans, Paper No. 195.
[223] Massachusetts Institute of Technology. (n.d.). *The Copenhagen Wheel*. Retrieved December 20, 2010, from SENSEable City Laboratory: http://senseable.mit.edu/copenhagenwheel/
[224] Ibid.

transportation and environmental policy decisions. The Copenhagen Wheel is expected to be commercially available in June 2011.[225]

3.7.1 Parking Applications

Parking applications enable the allocation of parking and loading/unloading areas to avoid unnecessary movements in urban areas. It can include infrastructure-to-vehicle communications for traveler information.[226] Technologies used can include central computer systems, DMS, garage monitoring systems, communications system hardware, and software.[227]

Figuring out how to value parking spaces "is of great interest to planners to aid in decisions which may promote or discourage automobile travel over public transit or walking and biking." Estimates for the number of existing parking spaces in the United States vary between 105 million and 220 million commercial parking spaces. One study on this issue estimates that there are approximately "three to four spaces per vehicle in particular urban settings." Another study by the University of California, Berkeley, set out to find a way to "properly value the total costs of automobile travel, including the emissions generated from constructing and maintaining parking spaces. Researchers developed five parking space inventory scenarios and performed a lifecycle environmental inventory for certain vehicle types (sedans, sport utility vehicles, and pickups) to calculate energy and GHG emissions. Depending on the scenario and vehicle type, "the inclusion of parking within the overall life-cycle inventory increases…greenhouse gas emissions from 230 to 380g CO_2e [carbon dioxide equivalent]…life-cycle SO_2 and PM10 emission show some of the largest increases, by as much as 24 percent and 89 percent from the baseline inventory."[228]

While the lifecycle emissions of constructing parking spaces have an environmental impact, drivers searching for spaces add to the impact. PGI is a way to provide real-time information to drivers concerning parking locations and availability. Drivers receive assistance in optimizing or re-routing themselves to an open location, which prevents excess emissions releases resulting from additional driving searching for a parking space. Currently, there are PGI systems in use in Europe, Japan, and the United States. Several case studies have been conducted on existing PGI systems.

- *Baltimore, Maryland:* The Baltimore-Washington International (BWI) Airport has the largest airport ITS parking system in the United States. Parking spaces in two daily garages with more than 13,000 total spaces are equipped with "ultrasonic sensors positioned over each parking space to monitor the availability of the space." Drivers are provided with parking availability at multiple points, including: "Open" or "Full" status signs on the airport access

[225] Ibid.

[226] EC-METI Task Force. (2009). *Methodologies for Assessing the Impact of ITS Applications on CO2 Emissions: Technical Report.* Brussels: EC-METI Task Force.

[227] U.S. Department of Transportation. (2000, May 30). *An advanced parking information system was deployed as part of the Seattle Metropolitan Model Deployment Initiative for $925,000; maintenance costs of the system hardware were estimated at 7% of the hardware capital costs.* Retrieved December 7, 2010, from ITS Costs Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/5EE5FD12EBAC108785256DF80070CB44?OpenDocument&Query=Home

[228] Chester, M., Horvath, A., & Madanat, S. (2010, July). Parking infrastructure: energy, emissions, and automobile life-cycle environmental accounting. Environmental Research Letters, 5(3). doi: 10.1088/1748-9326/5/3/034001

road; Billboard signs at each level of the two garages show the number of spaces available on each level; and "signs on the up and down ramps within the garage that indicate the number of spaces on floors above and below."[229]

- *Seattle, Washington:* The Seattle Advanced Parking Information System provides information and routing directions to three major parking centers via DMS. Information is also available via the Internet, phone, and pagers, and detection technology is used to monitor parking availability.[230]
- *Southampton, United Kingdom:* Drivers reduced the time spent searching for a parking space on average by 50 percent from 2.2 to 1.1 minutes.
- *Toulouse, France:* Toulouse city officials are planning to install 70 sensors that will monitor the availability of parking spaces. Information on the availability of spaces will be sent to drivers' cellular phones.[231]
- *Valencia, Spain:* Information provided through DMS influenced 61 percent of drivers. As a result, 30 percent changed their parking destination.[232]

While the environmental benefits of PGI systems were not found, it is reasonable to assume that reduced time spent searching for available parking can reduce energy consumption and emissions.

[229] U.S. Department of Transportation. (2007, January). *Advanced Parking Management Systems: A Cross-Cutting Study*. Retrieved January 13, 2010, from: http://www.its.dot.gov/jpodocs/repts_te/14318_files/study_site_desc.htm#bwi

[230] U.S. Department of Transportation. (2000, May 30). *An advanced parking information system was deployed as part of the Seattle Metropolitan Model Deployment Initiative for $925,000; maintenance costs of the system hardware were estimated at 7% of the hardware capital costs.* Retrieved December 7, 2010, from ITS Costs Database: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/0/5EE5FD12EBAC108785256DF80070CB44?OpenDocument&Query=Home

[231] UPI. (2010, December). French city plans parking space finder. Retrieved January 13, 2011, from: http://www.upi.com/Odd_News/2010/12/23/French-city-plans-parking-space-finder/UPI-63021293135094/

[232] UK Department for Transport. (2003, March). *Traffic Advisory Leaflet: Parking guidance and information .* Retrieved December 8, 2010, from Department for Transport: http://www.dft.gov.uk/pgr/roads/tpm/tal/its/arkingguidanceandinformation.pdf

4.0 Conclusions

Surface transportation is the fastest growing source of GHG emissions and the largest end-use sector emitting CO2, the predominant GHG. ITS can play an important role in reducing GHG emissions and providing air quality benefits. The results of research on the state of the practice of ITS applications that have shown environmental benefits are summarized below.

Demand and Access Management Applications

- ETC systems in the United States have demonstrated the ability to reduce emissions annually by up to 265,000 MTCE.
- Congestion pricing strategies employed internationally have shown the ability to reduce PM up to 20 percent, reduce CO_2 emission up to 14 percent, reduce NO_x up to 15 percent, and reduce the number of days that exceed air quality standards.
- While the acceptance of mileage based fee in the United States has not yet been determined, pilots have reduced VMT up to 13 percent, which in turn can reduce fuel consumption and emissions.

Eco-Driving Applications

- Eco-driving assistance studies and pilots have the potential to reduce CO_2 emissions up to 15 percent.
- Domestically and abroad, ACC pilot projects documented fuel reductions up to 10 percent and CO_2 and NO_x reductions of 3 percent. PM increased by 3 percent in one of the pilots.
- Navigation systems with eco-routing features have assisted drivers in improving fuel economy up to 15 percent.

Logistics and Fleet Management Applications

- AVL systems can assist in optimizing routes, which can reduce VMT, and therefore, emissions. One AVL/OBD technology solution eliminated 44,000 pounds of GHG emissions annually from the City of Napa's vehicle fleet.
- Idle-off stop-start systems can reduce emissions up to 20 percent in urban environments, and idle reduction technologies for freight rest stops have demonstrated the ability to reduce emission by 83 percent.
- Parking applications that provide information to drivers on the location of available parking spaces can halve the time spent searching. It is reasonable to assume that reduced time spent searching for an available space can also reduce fuel consumption and emissions.

Traffic Management and Control Applications

- Integrating traveler information with incident management systems can reduce emissions an additional 3 percent and improve fuel economy by 1.5 percent. Incident management programs around the United States have documented fuel savings of up to 6.83 million gallons per year.
- Studies in Minnesota proved that ramp metering projects in that state have reduced emissions by three to eight percent. Without ramp metering, emissions increase annually by 1,160 tons. However, ramp metering can have negative impacts on high demand days.
- Speed management applications in Europe have decreased NO_x emissions by up to 25 percent.
- Adaptive signal control can reduce emissions up to 50 percent for travel in the direction favored by the signal. Travel in the direction that is not favored by the signal can increase emission up to 9 percent.
- Traffic signal coordination and optimization can reduce emissions up to 22 percent and has a 40:1 return on investment.

Other Applications

- Bicycles used as field probes can collect and share fine scale, real-time environmental data and enable cities to make better transportation and environmental policy decisions.

Freight Applications

- UPS green delivery management initiatives have helped the company to eliminate 32,000 MTCE per year.
- Platooning freight vehicles has the potential to reduce fuel consumption by 10 to 20 percent.
- A Swedish trucking company reduced their fuel consumption by 5 to 20 percent using a real-time eco-driving performance monitoring system.

Transit Applications

- TSP studies conducted in England reported that bus emissions were reduced up to 30 percent, but non-transit vehicle emissions increased up to 11 percent.
- FTA research found that BRT elements can lead to up to 25 percent transit travel time savings in the United States, potentially increasing ridership and therefore reducing VMT and emissions.
- Researchers in China found that road segments with exclusive bus lanes have 10 percent less emissions of NO_x, CO, and PM compared to road segments without dedicated bus lanes.

While some environmental benefits have been documented from the use of ITS applications, additional research and assessments will need to be performed in order to ensure a robust set of standardized and accurate environmental data and performance results. Data documenting the environmental benefits of ITS applications are relatively limited and are presented in various metrics. Some benefits are documented in percentage reductions in emissions, fuel, or VMT as compared to a baseline. GHG emissions and air pollutant reductions are reported using a number of metrics, including MTCE, CO_2e, grams, and g/kWh. In order to accurately compare applications in terms of environmental benefits, a common metric will need to be used.

Additional research will need to be performed to determine what environmentally relevant data is available from cars, trucks, buses, and other vehicle modes. Once a baseline of available data is determined, it will be necessary to assess what types of data can make improvements in current models and algorithms. Providing relevant data to drivers is also a key factor in reducing surface transportation emissions. It is important to determine the best in-vehicle data to integrate with the transportation system and how to use that data to incentivize drivers to make greener transportation choices or facilitate network-wide “green” decision-making.

In terms of performance, it will be necessary to define the minimum environmental benefits that are acceptable for an individual application and/or a portfolio of applications, and by geographic scale (i.e. national, local, or corridor). Performance standards will help the AERIS Program to determine the applications that are viable for the future, candidates for more in-depth testing, and selection of applications for deployment.

APPENDIX A. List of Acronyms

3G	**Third Generation**
ACC	**Adaptive Cruise Control**
ADAS	**Advanced Driving Alert System**
AERIS	**Applications for the Environment: Real-Time Information Synthesis**
AFV	**Alternative Fuel Vehicle**
ALPR	**Automatic License Plate Recognition**
APC	**Automatic Passenger Counter**
AVL	**Automated Vehicle Location system**
BAA	**Broad Agency Announcement**
B100	**100 percent biodiesel**
B20	**20 percent biodiesel, 80 percent diesel blend**
BDS	**Bus Dispatch System**
BEV	**Battery Electric Vehicle**
BRT	**Bus Rapid Transit**
CAD	**Computer-Aided Dispatch**
CAN	**Controller Area Network**
CCTV	**Closed Circuit Television**
CMBS	**Collision Mitigation Braking System**
CMEM	**Comprehensive Modal Emissions Model**
CNG	**Compressed Natural Gas**
CO	**Carbon Monoxide**
CO_2e	**Carbon Dioxide equivalent**
C-TIP	**Cross-Town Improvement Program**
CVHAS	**Cooperative Vehicle-Highway Automation Systems**
CVISN	**Commercial Vehicle Information Safety and Networks**
CVO	**Commercial Vehicle Operations**
DMS	**Dynamic Message Sign**
DOT	**Department of Transportation**
DSRC	**Dedicated Short Range Communication**
DUAP	**Data Use Analysis and Processing**
E10	**10 percent ethanol, 90 percent gasoline blend**
E85	**85 percent ethanol, 15 percent gasoline blend**

ETC	**Electronic Toll Collection**
EV	**Electric Vehicle**
FCV	**Fuel Cell Vehicle**
FFV	**Flexible Fuel Vehicle**
FHWA	**Federal Highway Administration**
FMCSA	**Federal Motor Carrier Safety Administration**
FTA	**Federal Transit Administration**
GHG	**Greenhouse Gas**
GIS	**Geographic Information System**
GPRS	**General Packet Radio Service**
GPS	**Global Positioning System**
HC	**Hydrocarbons**
HEV	**Hybrid Electric Vehicle**
HOT	**High-Occupancy Toll**
ICM	**Integrated Corridor Management**
ITS	**Intelligent Transportation Systems**
JPO	**Joint Program Office**
km/h	**Kilometers per hour**
kWh	**Kilowatt hour**
LEZ	**Low Emission Zone**
LNG	**Liquefied Natural Gas**
LPG	**Liquefied Petroleum Gas**
mi/h	**Miles per hour**
MOVES	**Motor Vehicle Emissions Simulator**
MTCE	**Metric Tons Carbon Equivalent**
NGV	**Natural Gas Vehicle**
NH_3	**Ammonium Hydroxide (Ammonia)**
NO_2	**Nitrogen Dioxide**
NO_x	**Nitrogen Oxides (NO and NO_2)**
OBU	**On-Board Unit**
OEM	**Original Equipment Manufacturer**
PATH	**University of California Partners for Advanced Transit and Highways**
PEMS	**Portable Emissions Measurement Systems**
PGI	**Parking Guidance Information**

PHEV	**Plug-In Hybrid Electric Vehicle**
PM	**Particulate Matter**
SPaT	**Signal Phase and Timing**
TMC	**Transportation Management Center**
TSP	**Transit Signal Priority**
TTR	**Time-To-Red**
UPS	**United Parcel Service**
USB	**Universal Serial Bus**
U.S. DOT	**United States Department of Transportation**
V2I	**Vehicle-to-Infrastructure**
V2V	**Vehicle-to-Vehicle**
VMT	**Vehicle Miles Traveled**
VOC	**Volatile Organic Compound**
VRN	**Vehicle Registration Numbers**
VSL	**Variable Speed Limit**
Wi-Fi	**Wireless Fidelity**
WRI	**Wireless Roadside Inspection**
X2D	**Infrastructure-to-Device**

APPENDIX B. AERIS Sponsored Research

On June 17, 2010, the AERIS program launched the *Research on Intelligent Transportation Systems (ITS) Applications to Improve Environmental Performance* Broad Agency Announcement (BAA). The goal of the BAA is to identify contractors for: ongoing innovative research on ITS applications that improve environmental performance, and possible development of new applications; capturing and managing real-time data that are relevant to environmental applications development and performance measurement; and ongoing development and enhancement of evaluation techniques, performance measurement, and technologies to capture environmentally-relevant data.

Seven contractors were awarded under the BAA with a maximum performance period of one year. The awardees received up to $40,000 of Federal funding for their proposed research. Brief summaries of the research activities under each of the awarded contracts are found below. Research activities are currently taking place and will help to inform future AERIS activities.

1. *ECO-ITS*

The University of California, Riverside, previously conducted research and developed a microscopic emissions model, Comprehensive Modal Emissions Model, that is capable of predicting second-by-second fuel consumption and tailpipe emissions. The University's BAA research will build upon previous research in ITS and the environment to synthesize research results and recommend:

- Data collection methods.
- Environmental analysis methods.
- Integration of simulation and environmental modeling tools.
- Suggestions for environmental ITS applications and strategies.

The final deliverable will be a detailed technical report and recommendations.

2. *Developing Connected Vehicle Eco-Adaptive Signalized Intersection Algorithms*

Virginia Tech will develop and evaluate an innovative application for signal control using traffic simulation tools. Activities include:

- Conduct a literature review on key domestic and international studies.
- Develop Eco-Connected Vehicle applications at signalized intersections and advanced Eco-Connected Vehicle technology with inter-vehicle communication.
- Conduct traffic simulation runs in INTEGRATION, a model framework that evaluates the environmental impacts of ITS alternatives. The model combines a number of factors to estimate vehicle emissions from speed and acceleration levels. INTEGRATION will be used to evaluate the environmental benefits of adaptive Eco-Connected Vehicle technology at signalized intersections and advanced Eco-Connected Vehicle technology with inter-vehicle communication.

Virginia Tech will analyze the simulation results and will submit a final report.

3. *Research on ITS Applications to Improve Environmental Performance*

Mixon/Hill will investigate extracting environmentally relevant real-time data from vehicles and will then calculate performance measures based partly upon previous Clarus[233] and Michigan DOT Data Use Analysis and Processing (DUAP) research projects. Activities include:

- Identify available environmental data sets from ITS-equipped vehicles in Michigan DOT fleets.
- Work with the Michigan DOT and Mid-American Regional Council to determine the relevance and values of the data sets.
- Determine the gaps in available data.

Mixon/Hill will develop a preliminary system design plan for a transportation-relevant environmental data capture management system

4. *Engaging the International Community*

The University of California Partners for Advanced Transit and Highways (PATH) Program, located at the University of California, Berkeley, will collaborate with the international community through direct interactions and through support to the U.S. DOT. PATH will prepare for and attend the International Symposium on *Evaluation of CO_2 Emission Reduction with ITS Applications.* It will develop a technical report and action plan for U.S. DOT consideration based on United States, European, and Japanese experiences. The report will focus on:

- ITS applications and reference model.
- Traffic simulation and modeling.
- Emission modeling.
- Probe monitoring system.
- Validation methodology.
- International data warehouse.

5. *Developing and Evaluating Intelligent Eco-Drive Applications*

Virginia Tech and SAIC will develop and evaluate an innovative ITS application to improve environmental performance through extensions to an ACC capability. Activities include:

- Adapt the traffic simulation tool to model eco-ACC strategies.
- Construct sample transportation networks for testing these strategies.
- Conduct traffic simulation runs to evaluate the network-wide impacts of such strategies considering: (a) different levels of system market penetration; (b) different types of eco-driving strategies; (c) different network configurations; and (d) different levels of traffic demands.

Virginia Tech and SAIC will develop a final report summarizing the findings of the study.

[233] Clarus is the national surface transportation weather observation system; the system collects, quality checks, and distributes surface weather and road condition observations and provides access to these data sets to state and local transportation agencies and value-added commercial weather service providers.

6. ***An Evaluation of Likely Environmental Benefits of Lowest Fuel Consumption Route Guidance in Buffalo-Niagara Metropolitan Area***
The State University of New York (SUNY), University at Buffalo, will conduct a realistic assessment of the likely environmental benefits of a new application of environmentally-optimized route guidance for a medium sized metropolitan area. Activities include:

- Develop an integrated simulation modeling framework capable of calculating time-dependent fuel consumption factors.
- Use Transportation Analysis and Simulation System TRANSIMS and Motor Vehicle Emissions Simulator (MOVES) 2010 modeling to estimate environmental benefits to be expected from implementing low fuel consumption routing.
- Assess the impact of market penetration on the likely benefits of the strategy.
- Assess additional benefits to be expected from taking into account real-time information about traffic disturbances.
- Assess modal (i.e., passenger car versus truck) benefits.

7. ***Research on ITS Applications to Improve Environmental Performance***
The University of California, Riverside and Calmar, will investigate the use of real-time on-vehicle data to calculate environmental performance measures based partly upon the team's Comprehensive Modal Emissions Model (CMEM). Activities include:

- Determine the effort, scope, and geographic requirements and limitations required to transform the University of California, Riverside's, modeling structure from a static system into a real-time system.
- Contact commercial vehicle telemetry companies and summarize the general availability and types of data required for improved environmental monitoring.
- Evaluate data structures (data fusion requirements) and assess potential changes.

The UC Riverside – Calmar team will develop a technical report and recommendations.

APPENDIX C. Alternative Fuels and Alternative Fuel Vehicles

While the application of alternative fuels and AFVs do not necessarily involve the use of ITS technologies, they may offer additional emissions reductions when combined with ITS applications. This section provides information on the various types of AFVs and the environmental benefits of using alternative fuels in the appropriate vehicles. AFV types discussed are those as defined by the Energy Policy Act of 1992 and its amendments.

C.1 Flexible Fuel Vehicles

Flexible fuel vehicles (FFVs) are designed to operate on 100 percent gasoline, E85 (85 percent ethanol, 15 percent gasoline), or a mixture of both in the same fuel tank. The United States Department of Energy estimates that there are more than 8 million FFVs traveling on roads in the United States today.[234] Ethanol can be made from various feedstocks, including corn, sugar, switchgrass, and woody non-edible biomass. For many years, low level (10 percent or less) ethanol blends have been used to oxygenate gasoline, promoting "more complete combustion of the fuel, which can reduce exhaust emissions of carbon monoxide—a regulated pollutant harmful to human health—by 20 percent to 30 percent compared with pure gasoline."[235]

Additional environmental benefits from the use of E85 in FFVs include:

- Due to a large number of variables involved, studies show varying environmental benefits when comparing the tailpipe emissions of E85 to conventional gasoline. However, a 2008 study by the National Renewable Energy Laboratory "combined data from all applicable emissions studies into one robust data set." The analysis of the combined data set showed that "on average, all regulated emissions either decreased or showed no statistically significant difference with E85 compared with gasoline. Emissions that increased with the use of E85 included formaldehyde, acetaldehyde, and methane."[236]
- Researchers at the Argonne National Laboratory found that "corn-based E85 reduces GHG [lifecycle] emissions 17 to 23 percent below that of conventional gasoline on a per mile basis." Researchers also found that E85 reduces petroleum use by 70 percent.[237]

[234] U.S. Department of Energy. (2010, August 8). *Flexible Fuel Vehicles*. Retrieved December 20, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/flexible_fuel.html
[235] U.S. Department of Energy. (2010, February 24). *Flexible Fuel Vehicle Emissions*. Retrieved December 20, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/flexible_fuel_emissions.html
[236] U.S. Department of Energy. (2009, September 8). *E85 Emissions*. Retrieved December 20, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/emissions_e85.html
[237] Ibid.

- The "common oxygenate blend E10 (10% ethanol, 90% gasoline) has a higher vapor pressure than pure gasoline and thus produces higher evaporative emissions. E85's vapor pressure is lower than gasoline's, so it produces lower evaporative emissions."[238]

C.2 Natural Gas Vehicles

Natural Gas Vehicles (NGVs) are fueled by compressed natural gas (CNG) or liquefied natural gas (LNG). NGV systems are designed to run as either dedicated vehicles, meaning that they operate exclusively on CNG or LNG, or run as bi-fuel vehicles, where the vehicle has two separate fuel tanks from which it can operate: one for CNG or LNG, and one for gasoline.[239] It is estimated that there are approximately 110,000 NGVs traveling on US roadways today and 1,000 refueling stations.[240] However, the production of OEM NGVs has declined in recent years. The only OEM light-duty NGV available today is the Honda Civic GX, and it available only at select dealers. Around 11 EPA/California Air Resource Board-Certified retrofitters offer NGV conversion kits.[241]

In general, "dedicated NGVs demonstrate better performance and have lower emissions than bi-fuel vehicles because their engines are optimized to run on natural gas. In addition, the vehicle does not have to carry two types of fuel, thereby increasing cargo capacity and reducing weight."[242] Additional environmental benefits from the use of CNG in NGVs include:

- When compared to conventional gasoline, CNG offers significant emissions reductions:
  - CO is reduced 90 to 97 percent
  - CO_2 is reduced 25 percent
  - NO_x is reduced 35 to 60 percent
  - Non-methane HC is reduced 50 to 75 percent
  - Little to no PM emissions[243]

- When compared to diesel fuel, LNG offers significant emissions reductions:
  - CO_2 is reduced 25 percent, depending on the source of the natural gas

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[238] U.S. Department of Energy. (2010, February 24). *Flexible Fuel Vehicle Emissions*. Retrieved December 20, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/flexible_fuel_emissions.html

[239] U.S. Department of Energy. (2010, February 19). *What is a natural gas vehicle?* Retrieved December 20, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/natural_gas_what_is.html

[240] Natural Gas Vehicles for America. (2010). *Natural Gas Vehicles for America*. Retrieved December 20, 2010, from http://www.ngvc.org/

[241] Natural Gas Vehicles for America. (2010, May 21). *Guide to Available Natural Gas Vehicles and Engines*. Retrieved December 20, 2010, from http://www.ngvamerica.org/pdfs/marketplace/MP.Analyses.NGVs-a.pdf

[242] U.S. Department of Energy. (2010, February 19). *What is a natural gas vehicle?* Retrieved December 20, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/natural_gas_what_is.html

[243] U.S. Environmental Protection Agency. (2002). *Clean Alternative Fuels: Compressed Natural Gas (EPA420-F-00-033).* Washington, D.C.: U.S. EPA.

  - NO_x is reduced by at least 50 percent
  - PM is reduced by 50 percent
  - However, LNG can increase methane emissions[244]

- A study comparing CNG and diesel Washington Metropolitan Area Transit Authority transit vehicles found "CNG engines produced 49 percent lower nitrogen oxides emissions and 84 percent lower particulate matter emissions versus transit buses equipped with model year 2004 diesel engines."[245]
- The "City of Los Angeles Bureau of Sanitation LNG Heavy-Duty Trucks recorded a 23 percent reduction in nitrogen oxides emissions from dual-fuel LNG refuse trucks compared with diesel trucks. In an evaluation of freight trucks, CNG trucks produced 24 percent - 45 percent lower nitrogen oxides emissions and more than 90% lower particulate matter emissions compared with diesel trucks."[246]

C.3 Propane Vehicles

Propane vehicles run on liquefied petroleum gas (LPG). Most of the 270,000 on-road propane vehicles in the United States are used in fleets. Today, "most propane vehicles are conversions from gasoline vehicles. Dedicated propane vehicles are designed to run only on propane; bi-fuel propane vehicles have two separate fueling systems that enable the vehicle to use either propane or gasoline."[247] Propane fuel is stored on board the vehicle in a 300 pounds per square inch pressurized tank. The pressure turns the gaseous fuel into liquid form. OEM production of propane vehicles has declined, but it is possible to retrofit conventional vehicles and convert them to propane vehicles.

The use of LPG in propane vehicles can reduce emissions. The following are environmental benefits of LPG use, as compared to conventional gasoline:

- Researchers at the Argonne National Laboratory found that LPG used in light-duty propane vehicles reduced lifecycle GHG emissions by 21 to 24 percent and reduced petroleum consumption by 98 to 99 percent.[248]
- Reduced CO emissions by 20 to 40 percent.[249]

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[244] Ibid.
[245] Melendez, M., Taylor, J., Zuboy, J., Wayne, W. S., & Smith, D. (2005). *Emission Testing of Washington Metropolitan Area Transit Authority (WMATA) Natural Gas and Diesel Transit Buses (NREL/TP-540-36355).* Golden: U.S. DOE.
[246] U.S. Department of Energy. (2010, March 26). *Natural Gas Vehicle Emissions*. Retrieved December 20, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/natural_gas_emissions.html
[247] U.S. Department of Energy. (2010, February 19). *What is a propane vehicle?* Retrieved December 20, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/propane_what_is.html
[248] U.S. Department of Energy. (2010, April 21). *Propane Emissions*. Retrieved December 20, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/emissions_propane.html
[249] Wang, M. Q., & Huang, H. S. (1999). *A Full Fuel-Cycle Analysis of Energy and Emissions Impacts of Transportation Fuels Produced from Natural Gas.* Argonne: U.S. DOE.

- Reduced PM emissions by 80 percent.[250]
- VOC and NO_x emissions are equivalent to conventional gasoline, and methane increases by 10 percent.[251]

It is important to notes that a gallon of propane contains 25 percent less energy than a gallon of gasoline.

C.4 Electric and Hybrid Electric Vehicles

There are several types of electric vehicles and hybrid electric vehicles:

- *Hybrid Electric Vehicles (HEVs)* are powered by conventional or alternative fuels and an electric battery. The battery is charged through regenerative braking and the internal combustion engine.
- *Plug-In Hybrid Electric Vehicles (PHEVs)* are powered by conventional or alternative fuels and an electric battery. The vehicle is plugged in to charge the battery.
- *Dedicated Battery Electric Vehicles (EVs or BEVs)* are powered only by the electric battery. The battery stores electric energy that powers the motor.[252]

EVs, HEVs, and PHEVs all provide emissions reductions. Table C.1 compares the well-to-wheel emissions for a conventional gasoline vehicle, HEV, PHEV, and EV. Well-to-wheel is the term used for conducting the lifecycle assessment of transportation fuels and takes into account environmental impacts from the raw material sourcing for the fuel to use in the vehicle. Well-to-wheel emissions are important when calculating the emissions of vehicles that run partially or completely on electricity because the emissions calculated take into account the emissions generated from the electricity that is used to charge the battery. The table also shows the potential cost savings from operating one these AFVs versus a conventional gasoline vehicle.

[250] Wang, M. Q., & Huang, H. S. (1999). *A Full Fuel-Cycle Analysis of Energy and Emissions Impacts of Transportation Fuels Produced from Natural Gas.* Argonne: U.S. DOE.
[251] Ibid.
[252] U.S. Department of Energy. (2010, October 4). *Emissions from Hybrid, Plug-in Hybrid, and All-Electric Vehicles*. Retrieved December 21, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/electric_emissions.html

Table C-1. Well-to-Wheel Emissions and Fuel Costs for 100-mile Trip[253]
(Gasoline at $2.50/gallon; Electricity at $0.12 per kWh)

Vehicle	GHG Emissions (lbs. CO2e)	Costs
Gasoline (26.7 mpg)	75	$9.36
HEV (38.7 mpg)	52	$6.46
PHEV (38.7 mpg)	44	$4.84
EV	32	$2.40

C.5 Fuel Cell Vehicles

Fuel cell vehicles (FCVs) are powered by hydrogen fuel. These vehicles "are more efficient than conventional internal combustion engine vehicles and produce no harmful tailpipe exhaust—their only emission is water." While FCVs do not produce tailpipe emissions, it is important to note that the source of the hydrogen fuel, such as natural gas, can produce emissions. Production of FCVs and their fueling infrastructure are limited, but growing. The "U.S. Department of Energy is leading government and industry efforts to make hydrogen-powered vehicles an affordable, environmentally friendly, and safe transportation option."[254]

C.6 Biodiesel

Biodiesel is an alternative fuel that can be produced from a wide range of vegetable oils and animal fats. Biodiesel can be used is its pure form (B100) or can be blended with diesel fuel, such as B20 (20 percent biodiesel, 80 percent diesel). Blends of all levels can be used to fuel any diesel vehicle, and no retrofitting of the vehicle is necessary.

A 2002 study by the United States Environmental Protection Agency on biodiesel tailpipe emissions from heavy-duty vehicles found that "biodiesel decreases emissions of particulate matter (PM), carbon monoxide (CO), and hydrocarbons (HC) commensurately with its blend level." When compared to a conventional heavy-duty diesel operated vehicle, B20 reduces emissions of PM by 10.1 percent, CO by 11 percent, and HC by 21.1 percent. NO_x emissions did not change. As higher blends of biodiesel are used, PM, CO, and HC emissions continue to decrease, as shown in Figure 5 below.[255]

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[253] Ibid.
[254] U.S. Department of Energy. (2010, April 27). *Fuel Cell Vehicles*. Retrieved December 21, 2010, from Alternative Fuel and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/fuel_cell.html
[255] U.S. Department of Energy. (2009, July 10). *Biodiesel Emissions*. Retrieved December 28, 2010, from Alternative Fuels and Advanced Vehicles Data Center: http://www.afdc.energy.gov/afdc/vehicles/emissions_biodiesel.html

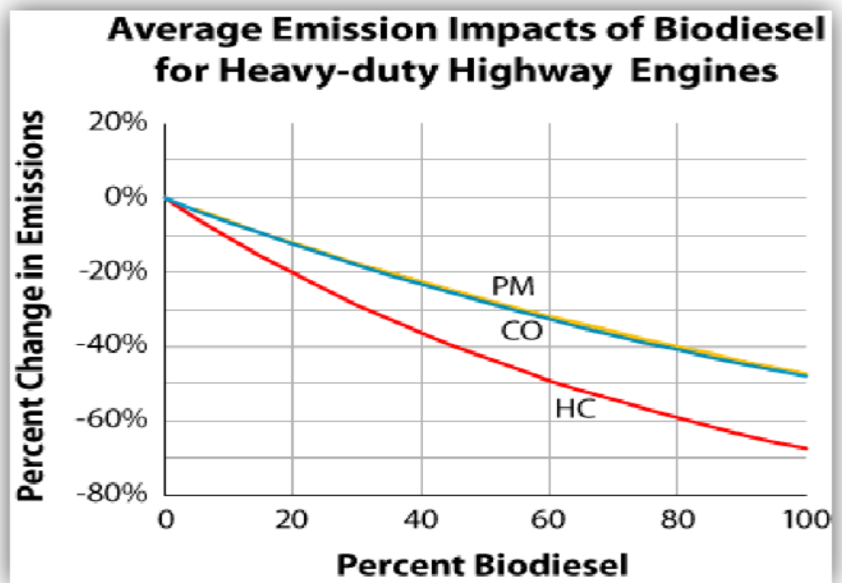


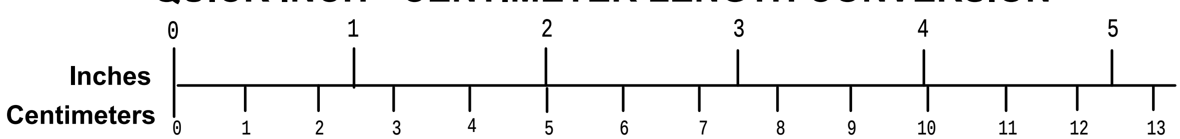
Figure C-1 – Average Emission Impacts of Biodiesel for Heavy-Duty Engines [256]

[256] Ibid.

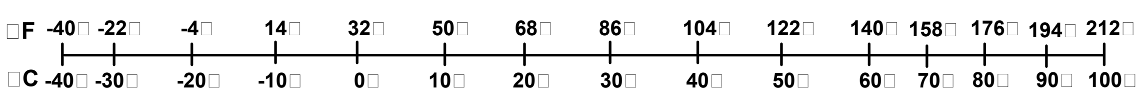
APPENDIX D. Metric/English Conversion Factors

ENGLISH TO METRIC			METRIC TO ENGLISH		
LENGTH (APPROXIMATE)			**LENGTH (APPROXIMATE)**		
1 inch (in)	=	2.5 centimeters (cm)	1 millimeter (mm)	=	0.04 inch (in)
1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
AREA (APPROXIMATE)			**AREA (APPROXIMATE)**		
1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)	1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)	1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
MASS - WEIGHT (APPROXIMATE)			**MASS - WEIGHT (APPROXIMATE)**		
1 ounce (oz)	=	28 grams (gm)	1 gram (gm)	=	0.036 ounce (oz)
1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kilograms (kg)
				=	1.1 short tons
VOLUME (APPROXIMATE)			**VOLUME (APPROXIMATE)**		
1 teaspoon (tsp)	=	5 milliliters (ml)	1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)			**TEMPERATURE (EXACT)**		
[(x-32)(5/9)] °F	=	y °C	[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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