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TRANSPORTATION ENERGY FUTURES SERIES

DEMAND

Effects of Travel Reduction and Efficient Driving on Transportation: Energy Use and Greenhouse Gas Emissions

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Transportation Energy Futures Series:

Effects of Travel Reduction and Efficient Driving on Transportation: Energy Use and Greenhouse Gas Emissions

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About the Transportation Energy Futures Project

This is one of a series of reports produced as a result of the Transportation Energy Futures (TEF) project, a U.S. Department of Energy (DOE)-sponsored multi-agency project initiated to identify underexplored strategies for abating greenhouse gases and reducing petroleum dependence related to transportation. The project was designed to consolidate existing transportation energy knowledge, advance analytic capacity-building, and uncover opportunities for sound strategic action.

Transportation currently accounts for 71% of total U.S. petroleum use and 33% of the nation's total carbon emissions. The TEF project explores how combining multiple strategies could reduce GHG emissions and petroleum use by 80%. Researchers examined four key areas – light-duty vehicles, non-light-duty vehicles, fuels, and transportation demand – in the context of the marketplace, consumer behavior, industry capabilities, technology and the energy and transportation infrastructure. The TEF reports support DOE long-term planning. The reports provide analysis to inform decisions about transportation energy research investments, as well as the role of advanced transportation energy technologies and systems in the development of new physical, strategic, and policy alternatives.

In addition to the DOE and its Office of Energy Efficiency and Renewable Energy, TEF benefitted from the collaboration of experts from the National Renewable Energy Laboratory and Argonne National Laboratory, along with steering committee members from the Environmental Protection Agency, the Department of Transportation, academic institutions and industry associations. More detail on the project, as well as the full series of reports, can be found at http://www.eere.energy.gov/analysis/transportationenergyfutures.

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AERIS	Applications for the Environment: Real-Time Information Synthesis
AWS	alternative work schedules
CAAA	Clean Air Act Amendments
CAPPA	Climate and Air Pollution Planning Assistant
CMAQ	Congestion Mitigation and Air Quality Improvement
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DOE	U.S. Department of Energy
DOT	departments of transportation
EERPAT	Energy and Emissions Reduction Policy Analysis Tool
EMFAC	Emissions Factor model
EPA	U.S. Environmental Protection Agency
FEA	Federal Energy Administration
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GHG	greenhouse gas
GPS	global positioning systems
GreenSTEP	Greenhouse Gas Statewide Transportation Emissions Planning Model
HOV	high-occupancy vehicle
IDAS	ITS Deployment Analysis System
IEA	International Energy Agency
ITS	intelligent transportation systems
MOVES	Motor Vehicle Emission Simulator Model
MPO	metropolitan planning organization
NCHRP	National Cooperative Highway Research Program
NHTS	National Household Travel Survey
PAYD	pay as you drive
PDA	personal digital assistant
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SCRITS	Screening Tool for ITS
SHRP	Strategic Highway Research Program
SOV	single-occupancy vehicle
TCM	transportation (air quality) control measures
TCRP	Transit Cooperative Research Program
TDM	transportation-demand management
TEF	Transportation Energy Futures
TRB	Transportation Research Board of the National Academies
TRIMMS	Trip Reduction Impacts of Mobility Management Strategies
TW	telework schedules
U.S. DOT	U.S. Department of Transportation
VHT	vehicle hours traveled
VMT	vehicle miles of travel
VTPI	Victoria Transport Policy Institute

Executive Summary

Addressing Effects of Travel Reduction and Efficient Driving on Transportation Energy Use and Emissions

Numerous transportation strategies are directed at reducing energy use and greenhouse gas (GHG) emissions by changing the behavior of individual drivers or travelers. These behavioral changes may have the effect of reducing travel, shifting travel to more efficient modes, or improving the efficiency of existing travel. This report reviews and summarizes the literature on relationships between these strategies and transportation-related energy use and GHG emissions.

The primary objectives of this report are to examine how changes to travel behavior can reduce transportation energy use and discuss the potential for federal actions to affect travel behavior. Since the 1970s, federal, regional, state and municipal agencies have tried to reduce energy use, emissions, and congestion by influencing travel behavior. This report summarizes historical findings documented in existing literature, as well as recent efforts that had not previously been reported, and highlights and interprets that literature for information most relevant to an energy perspective. Opportunities for federal action to encourage travel reduction and efficient driving as a way to reduce energy use are summarized in Table ES.1.

Table ES.1. Key Findings:
Opportunity Matrix for Travel Reduction and Efficient Driving Strategies

	Potential Payoff[a]		
Federal Authority	**Low (<0.5%)**	**Medium (0.5%-1.0%)**	**High (>1.0%)**
High	*Idle reduction*	*Transit improvements* *Nonmotorized improvements*	*Pricing (vehicle miles of travel or carbon fee)*
Medium	Education and marketing campaigns *Real-time traffic information* *Real-time transit and multimodal information*	*Pricing (congestion)* Employee commute options Ridesharing/vanpooling	Pricing (PAYD insurance) Eco-driving Speed limit reduction/ enforcement
Low	Parking management Carsharing	Telework/alt work schedules	

[a]Percentage shown for each column is an estimated range of energy or GHG reductions expressed as a percentage of total on-road energy and GHG. Strategies shown in italics are those in which a federal agency is currently taking an active role in working to implement.

The strategies considered in this report include the following:

- Road pricing, including fees on vehicle miles of travel (VMT), fuel and carbon taxes, congestion and cordon pricing, tolls, and pay-as-you-drive (PAYD) insurance
- Transit improvements, including expansion, promotion, and service improvements
- Nonmotorized improvements (infrastructure and programs)
- Parking pricing and management
- Work site trip reduction/employee commute options

- Telework and alternative work schedules
- Ridesharing and vanpooling
- Carsharing
- Education and marketing campaigns—mass, individualized, and social marketing
- Real-time transit and multimodal information
- Real-time traffic and parking information
- Eco-driving and information on vehicle maintenance
- Idle reduction
- Speed limit reduction/enforcement.

This summary is not intended to propose or advocate particular strategies.

Land use is discussed separately in a report on the built environment, so findings on land-use impacts are not included here unless they are part of a more inclusive package of strategies.

This report was developed under an NREL subcontract with Cambridge Systematics, which provided subject matter expertise. In addition to findings from the published literature, the report contains unpublished perspectives that are based on Cambridge Systematics experience.

Subject matter experts, including experts from U.S. Department of Transportation (U.S. DOT) and the U.S. Environmental Protection Agency (EPA), assisted the development of this report through consultation and review.

Strategies Vary in Effectiveness

The expected energy use and GHG emission reduction effects found in the reviewed literature vary widely from strategy to strategy. The estimated impact of individual strategies on surface transportation energy use and GHG emissions ranges from less than 1% to a few percent. We estimate the cumulative effect when travel behavior strategies are combined to result in a 7% to 15% reduction in energy use and emissions by 2030. Pricing strategies that are broadly applied have the greatest potential for substantial nearer-term effects. Over the long term (2030 to 2050), there may be potential for significant collective impact of a set of strategies such as land use, transit, nonmotorized improvements that are synergistic with road pricing strategies but not individually as significant in the shorter term.

Table ES.1 compares the level of federal regulatory and/or funding authority versus potential payoff of each strategy. Strategies for which an existing federal agency (in most cases, the U.S. DOT, and in a few cases, the EPA) is already taking an active role are shown in italics.

Table ES.2 summarizes the potential impact of combined strategies. The first line represents projected results from combining all strategies discussed in this paper. The rest of the table supplies estimates based on the different sets of strategies and assumptions explored in the individual reviewed studies.

Table ES.2. Estimates of Combined Strategy Impacts

Source	Impact[a]	Basis	Strategies Included
This study, based on information in U.S. DOT (2010c)	7-15%	On-road energy or GHG emissions in 2030	All strategies discussed in this report (see Table ES.1)
Cambridge Systematics (Urban Land Institute 2009)	3-11%	Surface transportation GHG emissions in 2030	Various bundles at “aggressive” levels of implementation
Greene, Baker, and Plotkin (2011)	1-8%	Light-duty VMT in 2035	Road user tax, carbon tax, PAYD, trip planning/route efficiency, ridesharing
ICF International (EPA 2011b)	3%	Light-duty vehicle GHG emissions in 2030	Transportation-demand management, transit, parking fees, mileage fees, land use
International Energy Agency (2005)	19%	On-road fuel savings in 2030	Transit, carpooling, telecommuting, compressed work week, eco-driving at very aggressive levels of implementation

[a] *Rounded to the nearest percent.*

Some Strategies have been Implemented, but More Could be Done

Many of these strategies—such as rideshare programs, employer trip-reduction initiatives, and programs to teach people to drive more efficiently—are already being implemented by a number of state, regional, and local transportation agencies. The federal government plays a role through research, education and outreach programs, transportation planning requirements, funding programs, and technical assistance. The level of political and financial support limit current levels of implementation of most of these strategies; they have not seen full implementation. Additional research and demonstration projects could provide insights needed to inform decisions on a given strategy and how to implement it most effectively.

The Challenges of Consumer Acceptance

Efforts to influence travel behavior to reduce energy use, emissions, and congestion can have a measurable impact on surface transportation energy use and GHG emissions, providing an important complement to strategies to improve vehicles and fuels. However, strong pricing or regulatory incentives would be needed to overcome issues of public acceptance and related challenges in changing behavior.

1. Introduction

Efforts to influence travel behavior in support of reducing energy use, emissions, and congestion have been undertaken since the 1970s. Many of these strategies are seeing renewed interest today for energy conservation and greenhouse gas (GHG) mitigation purposes. Others are being enhanced through the use of new technology, such as web-enabled mobile devices to collect real-time data and disseminate it to travelers.

This report, one of several addressing transportation demand in the Transportation Energy Futures (TEF) series, reviews and summarizes literature on strategies designed to change the behavior of individual drivers or travelers in order to decrease transportation-related energy use and emissions. The literature was identified based on the authors' prior work, especially based on the expertise of Cambridge Systematics authors, and emphasized literature most relevant to informing U.S. stakeholders about the types of travel behavior strategies that could reduce transportation energy use, the potential effectiveness of each strategy, and the potential role of the U.S. Department of Energy (DOE) in promoting or facilitating implementation of the strategy. Separate reports have been developed on the effects of urban form and the built environment on travel and energy, freight demand, and freight mode shares.

This report examines strategies directed at changing the behavior of individual drivers or travelers, including encouraging drivers to reduce the number of trips taken; use other modes of travel, including transit or nonmotorized transportation; and drive more efficiently. Most of the travel reduction strategies explored in this report affect passenger travel only, but some – notably the efficient driving strategies – also offer benefits for truck and freight travel. This report does not propose or advocate these strategies. The strategies covered in this report are shown in Table 1.1.

Table 1.1. Travel Reduction and Efficient Driving Strategies

Travel Reduction	Efficient Driving
Road pricing [vehicle miles traveled (VMT)] fees, fuel and carbon taxes, congestion and cordon pricing, tolls, pay-as-you-drive insurance)	Real-time traffic and parking information
Transit improvements (expansion, promotion, and service improvements)	Eco-driving and information on vehicle maintenance
Nonmotorized improvements (infrastructure and programs)	Idle reduction
Parking pricing and management	Speed limit reduction/enforcement
Work site trip reduction/employee commute options	
Telework and alternative work schedules	
Ridesharing and vanpooling	
Carsharing	
Education and marketing campaigns—mass, individualized, and social marketing	
Real-time transit and multimodal information	

The focus of this report is on strategies directed at individual drivers and vehicles, rather than system-level operational strategies affecting traffic flow characteristics, such as traffic signal coordination. The U.S. Department of Transportation (U.S. DOT) and Federal Highway Association (FHWA) continue to undertake research at the system-level. The report relies extensively on Cambridge Systematics' expertise in transportation analysis, and draws on a range of evidence, including empirically verifiable statements of fact, quantitative findings from published studies, as well as interpretations and judgments. This report addresses the following questions:

- What are the factors affecting travel behavior and how are they modeled? (Section 2.0)
- What methods and tools are available for assessing the impacts of strategies on travel behavior, energy, and GHG emissions? (Section 3.0)
- For each of the strategies listed in Table 1.1, what are the energy and GHG benefits, key uncertainties, other benefits and impacts, costs, interactions, development status, implementation, and barriers? (Section 4.0)
- What are the combined effects of travel reduction and efficient driving strategies on travel, energy, and GHG emissions? (Section 5.0)
- What federal actions have been taken in the past to influence travel reduction and efficient driving? What programs are currently underway, and what are possible future federal actions? (Section 6.0)
- What additional analysis is needed for understanding the effects of travel reduction and efficient driving strategies? (Section 7.0)

In addition, an annotated review of the literature, focusing on key sources that summarize research findings, is presented in the appendix.

2. Factors Affecting Travel Choices

In economic terms, the demand for travel is often framed as a derived demand, meaning that transportation is directly the outcome of engaging in activities and the need to reach destinations where those activities occur (Gomez-Ibanez, Tye, and Winston 1999). For instance, employees commuting to work, families taking a vacation, individuals going grocery shopping, and students attending school are all trips generated by activities taking place at the destination.

Once an individual decides to make a trip to a particular location, travel time and cost are the primary factors influencing which mode and what route he or she will take. The traveler may also consider factors such as the perceived reliability, comfort, convenience, and safety of the transportation service. The type and quality of information about the service or route may also influence decisions.

All of these factors refer to a set of generalized costs—including monetary, time, labor, discomfort, inconvenience, and other types of costs—that comprise theoretical foundation of travel behavior literature (Ortuzar and Willumsen 2002).

This section outlines key quantifiable and nonquantifiable factors that determine travel decisions, the role of personal and household characteristics in influencing choice, and the importance of time budgets. Finally, this section addresses how these factors are incorporated in predictive models.

2.1. Quantifiable Factors in Travel Choice

Travel time and travel cost are the best known and most studied factors contributing to travel decisions. The costs perceived by users have two main components: 1) monetary or out-of-pocket costs; and 2) the value of time spent traveling [Transit Cooperative Research Program (TCRP) 2002].

Monetary costs can include, but are not limited to, vehicle costs (including insurance, maintenance, depreciation, etc.), toll prices, fuel taxes, transit fares, and parking prices [FHWA 2011; Victoria Transport Policy Institute (VTPI) 2012].

The value of time spent traveling—total travel time cost—is the product of time spent traveling from door to door (measured as minutes or hours) multiplied by unit costs (measured as cents per minute or dollars per hour) (VTPI 2012; Small 1992).

Typically, travel time comprises in-vehicle travel time and out-of-vehicle travel time. In-vehicle travel time is the time spent in a car, on mass transit, or riding a bicycle. Out-of-vehicle travel time includes the access time to get to the mode; the wait time, especially with transit modes; transfer time if there are multiple modes; and the egress time from the travel mode to the final destination. Out-of-vehicle time is typically viewed as two to three times as onerous as in-vehicle time by the average traveler [U.S. Environmental Protection Agency (EPA) 2005].

In the case of planning for California High-Speed Rail, travel times included an access time (i.e., average time from point of origin to departure terminal), terminal time (i.e., average time spent at the departure or arrival terminal, including check-in time, walking to and from gates, and baggage pick-up), line-haul time (i.e., time the high-speed rail is in motion between stations), and arrival time (i.e., the average travel time from the terminal to the final destination) (California High-Speed Rail Authority 2005).

Another important factor is travel time reliability, or the certainty of the traveler arriving at the destination on time. Generally (and in support of common sense), research reviewed by Cambridge Systematics finds that travelers would rather arrive early than arrive late, and would often be willing to incur additional travel time to avoid late arrival. Quantitatively, travel time reliability is defined as the dispersion of travel time distribution. A risk-averse traveler would be willing to pay a monetary sum to decrease travel time uncertainty. Empirical estimates of the value of reliability range widely, but studies have shown that the value of unplanned time can range from one-half to three times the same unit of planned travel time

(Concas and Kolpakov 2009). This means that travelers value a minute lost due to an unplanned event (late bus, traffic incident, etc.) from one-half to three times as much as a minute that they expected to spend on their journey. In most cases, the value of an unplanned minute exceeds the value of a planned minute because of the risk of being late for a meeting or appointment or simply the frustration of an unexpected delay. The impact of reliability on mode choice or other travel decisions is not usually accounted for in travel forecasting models.

2.2. Nonquantifiable Factors in Travel Choice

The transportation research community acknowledges that there are a number of factors that contribute to individual travel choice, many of them difficult to quantify within the context of transportation modeling. These nonquantifiable factors, often characterized as “taste” in economic literature, can vary substantially from person to person, so it can be problematic to assign a general rule on how they affect travel choice. Nevertheless, factors affecting travel choice are not limited to the following:

Habit – The power of habit can be a strong factor influencing travel behavior (Goodwin 1977). The persistence of habit is often cited as a difficulty in decreasing society’s use of the automobile (Aarts, Verplanken, and van Knippenberg 1997).

Comfort – Comfort includes factors such as exposure to weather, noise, ride quality, and seating comfort. Espino, Ortúzar, and Román (2007) used a stated-preference survey to analyze the choice of bus versus automobile modes for suburban corridor trips in Gran Canaria, Spain, taking into account transit service comfort, travel time, prices (fares and parking fees), and transit service frequency. The analysis found that travel time cost values increase with transit service discomfort, and that travelers respond more to other incentives (increased transit frequency, lower transit fares, and increased parking fees) if transit service has high comfort levels. Crowdedness and cleanliness are additional subcomponents of this factor.

Convenience – Convenience factors include a network of well-maintained sidewalks to provide access to transit stops, well-designed and maintained platforms and shelters, and the ability to carry packages or travel with young children. According to a recent HNTB Corporation’s America THINKS transit survey (HNTB 2010), 29% of the Americans polled cited convenience as one of the biggest motivators for riding public transportation. When examining transit service quality from the passenger’s point of view, convenience is one of the main performance measures (U.S. DOT 1999a).

Better Information – Based on a review, Chorus et al. (2006) conclude that information provision can affect travel choices, but that its effect is limited due to several barriers. It is most influential when the traveler’s mindset is favorable, the information is readily available and of high quality, and the travel context is favorable. Mode choice is particularly hard to change because it is habitual and is often driven by soft factors such as status, rather than hard factors such as travel time gains. Stronger effects may be observed in the long term because of learning dynamics.

Social Influence, Prestige, and Green Choices – Axsen (2010) found that interactions with friends, families, and coworkers affect the way people make decisions, how they value the environment, and how lifestyle relates to purchase decisions.

Safety and Security – An individual may choose an alternative method of travel when a particular mode is perceived as dangerous or insecure (e.g., an elderly driver with poor eyesight, a young child traveling to school, a single woman in an all-male train car in the twilight hours).

All of these factors can play a role in encouraging modal shifts. For example, improved comfort and convenience, better information, and measures to improve safety at bus stops can play a role in increasing transit ridership. Similarly, measures to improve the perceived comfort and safety of walking and bicycling, such as traffic calming and separated bicycle facilities, can play an important role in encouraging use of these modes.

2.3. Time Budgets

The "travel time budget" theory, introduced in the 1970s by Yacov Zahavi, suggests that individuals have a stable and predictable average daily travel time, whether in an urban or rural area (Zahavi 1974). Comparisons across cultures that differ in historical time period and geographic location have found consistency in the amount of time people spend traveling. This is a result of people having fixed time budgets (24 hours in a day), in contrast to financial budgets, which are variable. Although travel time expenditures are commonly observed to be constant and measurable at the most aggregate level, other underlying behavioral elements are not as well understood (Mokhtarian and Chen 2004).

The concept of the travel time budget is appealing, although it is more a rule of thumb than proven with scientific evidence. For instance, Toole-Holt et al. (2005) found that time spent traveling increased at a rate of 1.9 minutes per person per day between 1983 and 2001, and that travel time rises with education and income.

Within a constrained time budget, the activity type can predict the amount of time spent traveling. Golob and McNally (1997) found that individual commute time is about 2.8 minutes per hour of work, that people travel about 7.8 minutes per hour of maintenance activities (e.g., essential shopping), and that for each hour of discretionary travel (e.g., to meet with friends and for recreational activities) men will travel 5.5 minutes and women will travel 8.5 minutes.

2.4. Role of Personal and Household Characteristics in Travel Choice

Individuals try to minimize both quantifiable and nonquantifiable generalized travel costs, but it is inevitable that everyone will generate some number of trips. The trips generated and choices of mode are dependent on a number of socioeconomic and demographic characteristics, such as household income, vehicle ownership, and household size and composition. For example, families with children may have trips such as travel to school or childcare, health care, or additional shopping. People with higher incomes tend to value time more highly relative to monetary cost. Gender and related societal norms can also be an influence; for example, most cyclists in the United States are male. In some cases, cultural background may influence mode choice; for instance, immigrants are more likely to take transit if it is the dominant form of travel in their native country (Blumenberg and Evans 2007). Market segmentation can be a useful tactic to help tailor travel reduction and efficient driving strategies and most effectively target different population groups.

The value of time typically varies based on differences in users' incomes. For transit riders, there is a distinction made between choice riders (those who have alternate means of travel, such as a car or bicycle) and captive riders (those who rely on transit as their sole means of transportation) (TCRP 2002).

2.5. Incorporation into Predictive Models

Factors influencing individuals' travel choices have been studied extensively: some have been integrated into standard travel demand models, and others modeled through elasticity-based analysis or qualitative assessments.[1]

Based on Cambridge Systematics' experience, nearly all metropolitan planning agencies, some state Departments of Transportation (DOTs), and other entities, such as researchers or transit agencies, maintain multi-step travel demand models that forecast traveler flows between traffic analysis zones across a network. These models are generally based on economic theories of rational choice. So-called "four-step" models are the most common and incorporate the following steps:

[1] Elasticities are informally adopted from the economist's understanding of price or service elasticity, and may be defined as the percentage change in the quantity of a commodity or service demanded by the public in response to a 1% change in price or service.

- During the trip generation step, socioeconomic and demographic variables are incorporated into a model (usually a regression model) that predicts the total number of trips generated by households, based on household characteristics (e.g., size, number of workers, auto ownership, income). Information on travel behavior from travel surveys is used to develop trip generation and trip attraction rates for each area.
- When the model performs trip distribution, it develops a trip table matrix that displays the number of trips from origin to destination zone for each purpose, based on the number trip generation and attractions per zone and the "impedance" between each pair of zones (reflecting the time and cost of travel by available modes).
- In the next step, mode choice, the demand model[2] determines which mode will be used for each trip based on the generalized cost for each mode, considering time, cost, and a "modal constant" that reflects unquantifiable factors. The mode chosen is also affected by the trip purpose. Mode choice is generally the most important step for travel reduction analysis, and mode choice factors from travel models are often used outside the four-step framework for this purpose.
- Finally, the trip assignment step assigns a number of travelers to each route and network link (a route is simply a chain of links between an origin and destination) based on relative travel times and costs.

More advanced forecasting models include features such as feedback loops from later steps to previous steps; additional steps, such as automobile ownership; or disaggregate destination choice models. Some take an entirely different approach that predicts trip chains or activity patterns (e.g., so that telework can be a choice) rather than just individual trips.

Transportation modelers have developed various "generalized cost" coefficients that include combined values of travel time, vehicle costs, toll prices, fuel taxes, transit fares, and parking prices. These are usually determined empirically for a specific community based on local travel behavior and user survey data. People's choices may be observed through surveys of actual travel behavior (known as revealed-preference data) or estimated based on responses to hypothetical choices (known as stated-preference data).

An important distinction in travel behavior analysis is between aggregate and disaggregate modeling. Aggregate analysis predicts behavior for a group of individuals or households (e.g., trip generation for households in a traffic analysis zone based on average income and auto ownership). Disaggregate analysis predicts the behavior of individual travelers or households. Models typically combine both approaches, although there is a trend of more advanced models taking an entirely disaggregate approach that simulates the decisions of a sample (or universe) of "synthetic" households that have been created with characteristics representative of actual households in the region. Fully disaggregate models more accurately reflect the various personal and system-level factors that influence travel behavior, rather than making generalizations based on average data.

In addition to multistep, network-based models, more simple or "sketch-plan" models have been developed for quick-response analysis of policy questions. These models are often based on data (coefficients, elasticities, etc.) taken from components of other models or from research efforts that involve the original development of mathematical models or factors. For example, elasticities are a common tool for "off-model" analysis. An elasticity is the ratio of a percent change in one factor (such as transit ridership) to the percent change in another (such as transit fare or service frequency). Elasticities are convenient, but it may be inappropriate to apply them in contexts that different significantly from that in which the elasticity was developed. For example, a 10% change in transit fare may have very different ridership impacts depending on the starting fare and available alternatives.

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[2] The functional form is often a binomial or multinomial logit.

Nonquantifiable factors are generally considered in travel forecasting models through a single "modal constant" that represents the collection of all non-time, non-cost factors for a given mode. This modal constant indicates how much one mode is preferred to another, assuming that time and cost are the same. The specific contributors to the modal constant, however, cannot be identified, making it difficult to model the effects of travel reduction strategies that work by affecting these factors, such as educational campaigns to change habits, or installation of bus shelters, benches, and lighting to make transit more convenient and safe. Surveys have been performed to gauge the relative importance of different factors, but the findings of such surveys have not been systematically incorporated into forecasting models.

3. Predictive Tools and Methods

This section includes an overview, based on Cambridge Systematics experience, of the various types of tools and methods used for predicting the energy and GHG impacts of travel reduction and efficient driving strategies, followed by an inventory and description of existing tools and methods.

3.1. Overview of Tools and Methods

In this report, methods for predicting the impacts of travel reduction strategies on energy and GHG emissions are grouped into four general categories:

1. Spatial or network-based travel demand forecasting models, including the four-step and activity-based travel demand models commonly used by metropolitan planning organizations (MPOs) and some state DOTs to forecast flows over a transportation network.

2. GHG inventory and policy analysis tools designed with a specific focus on estimating energy and GHG changes based on changes in travel and vehicle and fuel technology.

3. Other sketch-plan travel analysis tools, usually spreadsheets incorporating factors such as mode choice coefficients, elasticities, or case examples to predict behavioral changes. These tools focus primarily on trip reduction, VMT reduction or benefit-cost analysis outputs, but may also include fuel consumption and/or carbon dioxide (CO_2) emissions changes as outputs.

4. Energy and emission factor models, which are typically used in conjunction with travel models to translate travel impacts into energy and GHG impacts. These models may also be used on a stand-alone basis to assess the impacts of strategies that affect vehicle operating characteristics but not travel demand.

Underlying many of these tools are various mathematical and econometric techniques to predict behavioral changes, including:

- Mode choice models, often using a logit model formulation
- Trip generation models (including transit and nonmotorized trip generation) based on regressions on empirical data
- Elasticities based on econometric analysis of behavioral data
- Other econometric methods of analyzing survey data based on observed or stated behavior/choices.

Models that account for the effects of changes in vehicle operating characteristics are based on observed emissions data related to drive-cycle characteristics (e.g., instantaneous emissions regressed on vehicle speed, acceleration) or on physical models (e.g., power consumption). Traffic operations models (not described in this report) may be used to assess the impacts that changes in traffic flows or system operations strategies (such as congestion reduction) have on vehicle operating characteristics.

The universe of formal packaged tools for assessing travel reduction strategies, including energy and GHG impacts, is limited by the availability of robust data on strategy impacts and the extent to which key factors can be quantified. Traditional four-step, network-based models were developed primarily to analyze major highway and transit improvements and are poorly suited to analyze most transportation-demand management (TDM) strategies. Most models need additional calibration to provide accurate response to price changes (such as per-mile pricing or parking pricing), have too coarse a geography to model short walk and bicycle trips, and cannot address nonquantifiable factors (such as marketing, safety or convenience improvements) for reasons discussed in Section 2.0. Models in smaller metropolitan areas often do not include a transit component or simply remove transit trips from the highway network model based on factors, rather than modeling the transit network in detail.

For strategies that network-based models cannot readily represent, sketch-plan tools focus on worksite-based TDM and intelligent transportation systems (ITS) strategies. For other types of strategies, it is common for analysts to develop their own spreadsheet calculations using whatever data they can identify on the proposed strategies' market penetration and effectiveness, including elasticities (e.g., for pricing strategies) or case examples from research and demonstration studies. For example, for the *Moving Cooler* study of 49 transportation GHG reduction measures (Urban Land Institute 2009), a variety of methods were used, many of which relied on new spreadsheet formulations using assumptions based on available data and professional judgment.

Table 3.1, adapted from the Strategic Highway Research Program (SHRP) C09 report (PB Americas 2011), identifies which tools and methods apply to which types of strategies. The list of tools and methods is not comprehensive, but includes the types of models that are widely available in public use today. In some cases, similar types of models (e.g., four-step models using different software platforms) are grouped for convenience.

Travel analysis models must be used in conjunction with either an emissions factor model or some other source of fuel consumption or emissions data to estimate energy and GHG impacts. The preferred way of doing this is to use an accepted emission factor model, either the Motor Vehicle Emission Simulator model (MOVES) in most of the United States, or the Emissions Factor model (EMFAC) in California. These models account for local fleet and traffic speed characteristics, as well as current Federal fuel economy regulations. For strategies that reduce emissions primarily by reducing VMT, it is generally easier and still reasonably accurate simply to use average fuel economy factors (based on the latest Annual Energy Outlook projections, for example), which is how many of the tools described in Section 3.2 work. When using this simpler approach, the analyst must be careful to ensure that fuel consumption and emission factors are updated to correctly account for the latest federal and/or state fuel efficiency and alternative fuels requirements. Also, fuel blend (e.g., percent ethanol in gasoline) variations by state, region, and season need to be considered.

Table 3.1. Predictive Methods by Strategy

Tool or Method	Urban Transit Expansion	Nonmotorized Improvements	ITS/Operations and Management	Speed Management	Idle Reduction	Transit Service Improvements	Roadway Pricing	Land Use and Smart Growth	TDM and Public Education	Eco-Driving	Incorporation of GHG Emissions[b]
Travel Demand Models											
Four-Step Travel Demand Models	●[a]	●[a]				●[a]	●[a]	●			(4)
Activity-Based Models	●	●				●	●	●			(4)
Microsimulation Models	●	●	●	●		●	●	●		●	(4)
ITS Deployment Analysis System (IDAS)			●								(2)
GHG Inventory and Policy Analysis Tools											
Climate and Air Pollution Planning Assistant (CAPPA)	●	●			●	●	●	●	●		(3)
GreenSTEP	●	●	●			●	●	●	●		(2)
Energy and Emissions Reduction Policy Analysis Tool (EERPAT)	●	●	●			●	●	●	●		(2)
Other Sketch Analysis Tools											
COMMUTER						●	●		●		(3)
TRIMMS						●	●		●		(1)
SCRITS			●								(3)
SPASM	●					●	●				(2)
Emission Factor Models[c]											
MOBILE6					●						(3)
MOVES			●	●	●						(1)
EMFAC			●	●	●						(2)

[Source: Adapted from SHRP C09 report (PB Americas 2011).]

[a] Denotes features not found in many of the more basic regional travel demand models. "Enhanced" regional travel demand models may include some or all of the following: transit networks and mode choice, nonmotorized conditions and mode choice, consideration of time-of-day shifting, a freight model, or feedback improvements to better capture network effects.
[b] Incorporation of GHG emissions: 1) MOVES emission rates; 2) other speed-fuel economy or speed-emissions relationship; 3) fixed-fuel economy or CO_2 emissions factor per vehicle-mile; 4) GHG emissions are not produced by the model but can be calculated from travel outputs using various methods.
[c] These models can be used to obtain emission factors that are applied to reductions in travel (VMT and/or trips) from any strategy. In addition, the bullets indicate models that are suitable for assessing changes in traffic flow/vehicle operations.

3.2. Inventory of Travel Demand Tools, Related Models and Methods

This inventory reviews major tools, models, and methods that can be used to estimate travel demand and effects of changed policy or economic conditions on travel demand. Specific resources documenting each type of tool, model, or method appear at the end of the associated section. Tools selected for inclusion in this section, as well as synthesis, perspectives, judgments, and previously unpublished information, rely upon Cambridge Systematics experience in the field.

3.2.1 Travel Demand and Related Models

3.2.1.1. Four-Step and Activity-Based Travel Demand Models

Overview: Traditional four-step models are used in regional- and project-level planning to forecast transportation network flows and traffic conditions based on socioeconomic projections (population, households, jobs by type), as well as alternative transportation networks and facility characteristics. These models have many variations and additional steps (such as auto ownership) have evolved into more advanced network approaches that model traveler activity patterns rather than individual trips.

Developer/Owner: Typically developed and applied by state and regional transportation agencies (DOTs and MPOs) using commercially available software. All MPOs are required to maintain travel demand forecasting models for use in transportation planning and, if needed, air quality analysis. A number of state DOTs also maintain statewide models.

Extent of Use: See above.

Intellectual Property Rights and Transparency: Software platform is typically licensed for use by public agency. Input data and methods are documented in the public domain.

Major Inputs: Highway and transit networks, socioeconomic and demographic projections by traffic analysis zone, various behavioral parameters (e.g., trip generation rates by household type, mode choice coefficients).

Major Outputs: Traffic volumes and speeds by network link (which can be summarized at a subarea- or regional-level); trips, VMT, and passenger-miles of travel by mode. VMT and speed outputs can be used in conjunction with emission factor models or fuel consumption rates to estimate energy and GHG.

Strengths: These models often estimate the effects on mode shifting of travel reduction strategies, particularly those that affect the time and cost of travel. They are best suited for major infrastructure project evaluation, such as new transit investments. They can be used with emission factor models to capture network-level effects on traffic flow (e.g., from reduced congestion). Activity-based models can model additional strategies, such as telecommuting, that do not involve travel.

Weaknesses: These models are not well suited for analyzing most TDM/travel reduction strategies. They require expert implementation and can be time-consuming to set up and run. Trip generation and trip distribution are often not tied to any policy factors, only mode choice. These models are often not calibrated to account for the impacts of pricing strategies. Most operate at a geographic scale that is too aggregated to capture the effects of bicycle and pedestrian improvements, and they are not able to directly capture the effects of informational campaigns. However, if changes in trips can be estimated "off model," and the changes in trips are large enough, these models can be used to assess network-wide effects on traffic flow.

Scope:

- Temporal – Typically run for a base year and one or more future years up to 20 to 25 years out for long-range planning purposes.
- Geographic – Typically metropolitan or statewide. May be used at a smaller scale (e.g., corridor).

- Modal, Vehicle, Fuel – Always highway, sometimes transit, occasionally bike/pedestrian. Multimodal models are more common in larger metro areas. Vehicle and fuel choices are not modeled.

Resources: For an example of the use of a travel demand model for GHG analysis, see: Sun, W., J. Ortega, and R. Curry. "Impact of Transportation Demand Management Policies on Green House Gas Emissions: A Modeling Approach." Presented at the 12th Transportation Research Board of the National Academies (TRB) Transportation Planning Application Conference, May 18, 2009 (Sun, Ortega, and Curry 2009).

For a discussion of advanced practices in travel demand forecasting, including integration with emissions models, see: Donnelly, R., et al. "Advanced Practices in Travel Forecasting." *National Cooperative Highway Research Program (NCHRP) Synthesis 406*, Washington, D.C.: National Research Council, 2010 (Donnelly et al. 2010).

3.2.1.2. Microsimulation or "Intelligent Agent" Models

Overview: Microsimulation models resemble conventional four-step travel demand models. They couple a conventional trip generation module with an extremely detailed representation of an urban road network. The model can then simulate the movement of every individual vehicle, as it is piloted by a software agent. The agent is aware of surrounding vehicles and dynamically reacts to traffic situations according to a set of predefined rules. Microsimulation models may be linked with emissions models, such as MOVES (2012), to reflect second-by-second operating characteristics and emissions.

Developer/Owner: The most widely known microsimulation model is the Transportation Analysis Simulation Model (FHWA 2012) developed for the U.S. DOT and FHWA. Other models of more limited scope have been developed for research purposes.

Extent of Use: TRANSIMS is in use on a test basis in a few areas, including Buffalo, New York; Champaign-Urbana, Illinois; and Dallas-Fort Worth, Texas.

Intellectual Property Rights and Transparency: TRANSIMS is open source and freely available through FHWA.

Major Inputs: Population characteristics, land use, and employment data; household activity profiles; transportation networks with detailed representation of lane configurations, traffic controls, speeds, etc.

Major Outputs: VMT, vehicle hours traveled (VHT), modal shares, travel speeds, congestion metrics and emissions (if linked with an emissions model).

Strengths: Microsimulation models are particularly effective for modeling measures the effectiveness of which may hinge on vehicle-to-vehicle interactions or the dynamic behavior of traffic. If one driver adopts eco-driving techniques, she will save fuel, but what happens to traffic conditions if most drivers eco-drive? Different eco-driving algorithms can be tested under varying conditions. These models are also useful for studying congestion mitigation measures and smart-vehicle algorithms aimed at congestion or safety.

Weaknesses: These models tend to be expensive to build, maintain, operate, and interpret. They generate enormous volumes of sometimes hard-to-interpret data.

Scope:

- Temporal – Similar to four-step models, 20- to 30-year forecasts are typically available.
- Geographic – Regional.
- Modal, Vehicle, Fuel – On-road vehicles; vehicle/fuel type distinctions can be incorporated.

Resources:

- TRANSIMS website (FHWA 2012).
- Transportation Research and Analysis Computing Center at Argonne National Laboratory.

3.2.1.3. Intelligent Transportation Systems Deployment Analysis System (U.S. DOT)

Overview: ITS Deployment Analysis System (IDAS) is a tool to estimate the impacts, benefits, and costs resulting from the deployment of ITS components. IDAS interfaces with regional travel demand model output and can be used to estimate CO_2 emissions, as well as other impacts.

Developer/Owner: Developed for FHWA by Cambridge Systematics, Inc.

Extent of Use: Has been used in various ITS planning studies around the United States.

Intellectual Property Rights and Transparency: Model is available for purchase through McTrans. Documentation is available.

Major Inputs: Travel demand model output; extent of deployment of individual ITS strategies (including spatial/network links where appropriate).

Major Outputs: Changes in delay, fuel consumption, CO_2 emissions, and other impacts.

Overview of Calculations: ITS impacts based on sketch-level factors from available data (e.g., strategy X produces a y% reduction in travel delay).

Scope:

- Temporal – Consistent with travel demand model data.
- Geographic – Regional.
- Modal, Vehicle, Fuel – On-road vehicles, no vehicle/fuel type distinctions.
- Strengths – Can capture network-level effects of ITS strategies, including traveler information.
- Weaknesses – Limited by available evaluation data. Impact data and emission factors have not been updated recently; fuel consumption estimates do not account for recent fuel economy standards. Most strategies are operations-focused (e.g., traffic signal timing) and outside the scope of this report.

Resources:

- Cambridge Systematics, Inc. "IDAS – User's Manual." Prepared for FHWA (IDAS).
- FHWA web site: http://ops.fhwa.dot.gov/trafficanalysistools/idas.htm (U.S. DOT).

3.2.2. GHG Inventory and Policy Analysis Tools

3.2.2.1. Climate and Air Pollution Planning Assistant (CAPPA)

Overview: CAPPA is a simple spreadsheet-based tool to estimate the GHG benefits of a wide variety of policies and strategies, including travel reduction, vehicle and fuel technology, and non-transportation strategies. It focuses on methods that can be implemented at a municipal level, helping jurisdictions choose a suite of combined measures to meet reduction goals, rather than modeling the impact of any single measure in a detailed way. It includes more than 100 municipal actions, such as vehicle fleet purchases and LED traffic signal replacement, in addition to community actions, such as transit-oriented development and bicycle programs. There are three transportation subcategories: alternative fuels, trip reduction, and vehicle fuel efficiency (ICLEI).

Developer/Owner: ICLEI

Extent of Use: Unknown, primarily municipal.

Intellectual Property Rights and Transparency: Available to the public; spreadsheet tool is transparent.

Major Inputs: Various parameters related to market size and extent of strategy application, and traveler response factors (such as increased transit ridership or nonmotorized travel) for each strategy.

Major Outputs: Changes in GHG emissions.

Overview of Calculations: The model typically applies user-input market size and response factors to calculate GHG emissions changes based on changes in fuel consumption by vehicle type. The model includes some default data.

Scope:

- Temporal – Emission factors based on current/recent data.
- Geographic – Intended for use at municipal level, but could be applied at any geographic scale.
- Modal, Vehicle, Fuel – Transit, bicycle, and pedestrian strategies included. Strategies include alternative fuel fleet vehicle purchases (including transit and municipal service/utility vehicles as well as passenger vehicles). Emission factors for biofuels are included.

Strengths and Weaknesses:

- Strengths – Intended as a simple calculation tool to estimate GHG reductions from a wide range of strategies.
- Weaknesses – Not a predictive model of traveler response —relies on user inputs or gross default assumptions from other areas.

Resources:

- ICLEI website: http://www.icleiusa.org/tools/cappa. (ICLEI).
- CAPPA User Guide (2010): http://www.icleiusa.org/action-center/tools/ICLEI_CAPPA_User_Guide.pdf.

3.2.2.2. GreenSTEP

Overview: Initially developed for Oregon, GreenSTEP is a state-level model designed to estimate the effects of policy changes on factors that influence GHG emissions, including metropolitan population densities and relative amounts of urban and rural development; capacity and use of transit service and highways; use of alternative fuel or technology vehicles, vehicle fuel efficiency, and future market share of efficient automobiles; the carbon content of fuels and fuel costs; potential VMT-based fees and other vehicle charges; and GHG emissions from electrical power generation. GreenSTEP also allows modeling of several types of travel demand management and has the potential for switching more travel to bicycles and other light weight vehicles (e.g., electric bicycles).

Developer/Owner: Brian Gregor, Oregon DOT.

Extent of Use: GreenSTEP is used for policy analysis in Oregon. FHWA is adapting GreenSTEP for use elsewhere.

Intellectual Property Rights and Transparency: Publicly available, open-source, documentation available.

Major Inputs: Household participation in carsharing, pay-as-you-drive (PAYD) insurance, employer-based commute, and individualized marketing programs; driver participation in eco-driving; types of vehicles owned by household (including bicycles) and average fuel economy; household average fuel costs, gas tax, and other costs; fuel proportions by vehicle type; freeway lane miles and transit revenue-miles; population densities and mixed use by census tract; and user-input changes in truck traffic growth rates.

Major Outputs: Changes in VMT, fuel consumption, electric power consumption, GHG emissions, and variable travel costs for different scenarios.

Overview of Calculations: Household-level model based on a synthetic household and vehicle population. A household budget model is used to calculate the effects of changes in costs on VMT. Vehicles are assigned VMT within households. Factors are included for participation in other types of travel reduction or efficient driving activities and benefits. GHG emissions are based on fuel economy by type and model year with adjustments for congestion using speed-fuel economy relationships from MOVES.

Scope:

- Temporal – Through 2050.
- Geographic – Statewide, nonspatial. Oregon DOT plans to develop a metropolitan area version.
- Modal, Vehicle, Fuel – Light and heavy highway vehicles and transit (bus and rail). Truck VMT is not affected by any policy variables except user-input growth rates, but the Oregon DOT plans to add long-distance travel and freight models. Alternative fuels, plug-in hybrid electric vehicles, and electric vehicles included.

Strengths and Weaknesses:

- Strengths – Model is specifically designed for GHG policy analysis and has many policy levers. Synthetic household population allows for market segmentation of some policy effects and consideration of characteristics of alternative fuel vehicles. It does not require network/spatial information.
- Weaknesses – Quality of data on strategy impacts is limited to available data (e.g., eco-driving participation and effects). Estimates only aggregate relationships (e.g., between road capacity and VMT; public transit use assumed proportional to service levels), so for specific major investments, a network-based forecasting model would be preferable to this method. Would require significant time and data investment for a new user.

Resources:

- Gregor (2010). "Greenhouse Gas Statewide Transportation Emissions Planning Model (GreenSTEP Model) Documentation." Oregon Department of Transportation, September 2010.

3.2.2.3. Energy and Emissions Reduction Policy Analysis Tool (EERPAT)[3]

Overview: The EERPAT is a statewide policy analysis tool for providing rapid analysis of many scenarios that combine effects of various policy and transportation system changes, including those that are often difficult to analyze using traditional transportation system analysis tools.

Developer/Owner: FHWA; developed by RSG, Inc.; is based on Oregon DOT's GreenSTEP model.

Extent of Use: EERPAT was released in early 2012 and has been piloted in Florida.

Intellectual Property Rights and Transparency: Publicly available, open-source, documentation available.

Major Inputs: Similar to GreenSTEP.

Major Outputs: Similar to GreenSTEP.

[3] This description is based on a draft description provided by FHWA. Model documentation was not available at the time of this writing.

Overview of Calculations: Similar to GreenSTEP.

Scope:

- Temporal – Through 2050.
- Geographic – Statewide, nonspatial.
- Modal, Vehicle, Fuel – Similar to GreenSTEP.

Strengths and Weaknesses:

- Strengths – Provides policy sensitivity for different GHG mitigation measures, including carbon taxes, technology solutions, transit, and demand management; can evaluate future changes in land use and is sensitive to external changes in the price of fuel; can incorporate changes in technology, such as increased use of electric vehicles or plug-in hybrids; and can be used to assess the overlapping effects of bundles of GHG mitigation strategies.
- Weaknesses – VMT estimates are attributed to the regions where the households are located instead of where the travel occurs; and the model does not include trips originating outside of the state. Also, there are a large number of model inputs and some may be difficult to obtain, such as the battery range of electric vehicles, percentage of workers paying for parking, percentage of employers with strong employer-based programs, and percentage of households subject to strong TDM programs.

Resources:

- Tool and documentation to be available at: http://www.environment.fhwa.dot.gov.

3.2.3. Other Sketch-Plan Travel Analysis Models

3.2.3.1. COMMUTER

Overview: COMMUTER is a spreadsheet designed to analyze the impacts of employer- or worksite-based TDM programs and transit improvements on VMT, criteria pollutant emissions, and CO_2. It is based on the FHWA TDM Model developed in the early 1990s, which had a less user-friendly DOS-based interface, and did not include emissions calculations, but included market segmentation by allowing specification of different zone-zone pairs with associated characteristics.

Developer/Owner: EPA (developed by Sierra Research, Cambridge Systematics, and the Eastern Research Group).

Extent of Use: Has been used by a number of MPOs, DOTs, and other agencies for analysis of worksite TDM strategies.

Intellectual Property Rights and Transparency: Available free of charge, thoroughly documented. Programmed in Excel workbook with Visual Basic interface.

Major Inputs: Size of affected worker population; baseline mode shares and trip lengths; local emission factors (optional); TDM strategy characteristics, such as changes in time and cost of travel by mode, level of “soft” strategies offered, and telecommuting participation.

Major Outputs: Changes in VMT, vehicle-trips, air pollutant emissions, fuel consumption, and CO_2 for affected worker population.

Overview of Calculations: Effects of time and cost changes are calculated using a “pivot-point” version of the logit mode-choice model, which requires knowing only baseline mode shares and the change in time and cost by mode. Other strategies (e.g., information/outreach) are based on lookup tables or parameters from literature. Fuel consumption is a straight average rate based on MOBILE6 fuel consumption factors.

Scope:

- Temporal – Various future years can be specified for built-in air pollutant emission factors. Otherwise, analysis is non-temporal.
- Geographic – Site-based or areawide analysis may be conducted.
- Modal, Vehicle, Fuel – Light-duty vehicles only; no alternative fuels.

Strengths and Weaknesses:

- Strengths – Easy to use. The model can also be adapted for sketch-level analysis of general response to pricing policies or to measures that affect travel time. Pivot point is a robust way of estimating mode share changes at a sketch level because it utilizes coefficients from travel demand models.
- Weaknesses – Data for estimating effects of "soft" strategies are generally based on expert judgment with factors primarily developed two decades ago. Emission/fuel consumption factors have not been updated to account for new fuel economy standards. Nonspatial/aggregate input data and predictions.

Resources:

- Model and documentation available on the EPA's website: http://www.epa.gov/otaq/stateresources/policy/pag_transp.htm#cp

3.2.3.2. TRIMMS

Overview: The Trip Reduction Impacts of Mobility Management Strategies Model (TRIMMS) is a spreadsheet model to predict trip, VMT, fuel, and emissions impacts for worksite-based TDM programs. It has many similarities to the COMMUTER Model but uses somewhat different methodologies. The model also is intended for cost/benefit assessment and incorporates damage costs for various pollutants.

Developer/Owner: Center for Urban Transportation Research at the University of South Florida

Extent of Use: Unknown, but possibly comparable to COMMUTER although it has not been in existence as long. Recently used for an EPA national study of GHG reduction measures through application to 15 cities and extrapolation to national scale.

Intellectual Property Rights and Transparency: Available for public use, and methods documented.

Major Inputs: Size of affected worker population by industry sector; baseline mode shares and trip lengths (defaults provided); TDM strategy characteristics for employer support programs, financial and pricing strategies, and access and travel time improvements. Default benefit and cost parameters can be customized.

Major Outputs: Changes in vehicle trips and VMT, air pollution and GHG emissions; changes in costs of air pollution, GHG emissions, congestion, health, safety, and noise

Overview of Calculations: Relies on elasticities (including modal cross-elasticities) to estimate impacts of time and cost strategies. Impacts of "soft" strategies/supporting programs (e.g., advertising, telecommuting, guaranteed ride home) are based on econometric analysis of Washington State's trip reduction program database. Model version 2.0 and higher includes a sensitivity analysis component. Model version 3.0, released in January 2012, incorporates emission factors (including CO_2-equivalent emissions) from MOVES (2010a).

Scope:

- Temporal – Parameters provided for current/recent year.

- Geographic – Site-based or area-wide analysis may be conducted. Default parameters provided for 85 metropolitan areas.
- Modal, Vehicle, Fuel – Light-duty vehicles only; no alternative fuels.

Strengths and Weaknesses:

- Strengths – Easy to use. The model can also be adapted for sketch-level analysis of general response to pricing policies or to measures that affect travel time. More robust data to support evaluation of "soft" strategies than COMMUTER Model. Speed-based fuel economy equation.
- Weaknesses – Nonspatial/aggregate input data and predictions.

Resources:

- Concas, S., and P.L. Winters (2009). *Quantifying the Net Social Benefits of Vehicle Trip Reductions: Guidance for Customizing the TRIMMS© Model.* Center for Urban Transportation Research, University of South Florida. http://www.nctr.usf.edu/abstracts/abs77805.htm.
- EPA (2011a). *Analyzing Emission Reductions from Travel Efficiency Strategies: A Guide to the TEAM Approach.* Prepared for EPA by ICF International, EPA-420-R-11-014.

3.2.3.3. Screening Tool for ITS (SCRITS)

Overview: SCRITS is a spreadsheet tool developed by FHWA for evaluating ITS strategies at a screening level when a more sophisticated evaluation using a tool, such as IDAS, cannot be performed. Primary focus is on user benefits. The tool includes 16 ITS applications.

Developer/Owner: FHWA Office of Traffic Management and ITS Applications (developed by SAIC).

Extent of Use: Unknown. Cambridge Systematics used it once for an air quality evaluation for Tennessee DOT.

Intellectual Property Rights and Transparency: Freely available, unlocked spreadsheet with user manual.

Major Inputs: Baseline study area VMT and VHT, volume-capacity ratios, extent of deployment of various ITS strategies.

Major Outputs: Changes in VMT, VHT, emissions (not including CO_2), energy consumption, costs.

Overview of Calculations: Workbook format that uses lookup tables to draw data on impacts of various strategies. Fuel consumption changes based on fuel-consumption-per-mile rate.

Scope:

- Temporal – Not specified.
- Geographic – The analysis should be adaptable to regional, corridor, facility, and subarea scales.
- Modal, Vehicle, Fuel – Highway vehicles (light and heavy), no fuel segmentation.

Strengths and Weaknesses:

- Strengths – Easy to use sketch-planning tool for ITS strategies.
- Weaknesses – The model was developed over a decade ago and has not been updated with more recent data, but could be updated by the user. Documentation notes that "there is a great deal of uncertainty regarding the effects of ITS applications."

Resources:

- Science Applications International Corporation. "User's Manual for SCRITS – SCReening Analysis for ITS." Prepared for Federal Highway Administration (U.S. DOT 1999b).
- FHWA website – http://www.fhwa.dot.gov/steam/scrits.htm (U.S. DOT).

3.2.3.4. Sketch-Planning Analysis Spreadsheet Model (SPASM)

Overview: SPASM is designed to assist planners in sketch-planning analyses of packages of transportation actions at the system and corridor level, including transit system improvements, highway capacity improvements, high-occupancy vehicle (HOV) improvements, and auto use disincentives. It is primarily intended as a cost/benefit model.

Developer/Owner: FHWA (developed by Cambridge Systematics).

Extent of Use: Unknown, probably not widespread.

Intellectual Property Rights and Transparency: Freely available, unlocked spreadsheet with user manual.

Major Inputs: Unit costs, impact rates (e.g., energy and emission factors), agency costs, facility information (e.g., segment length, capacity, free-flow speed by mode), demand factors (e.g., person-trips, vehicle occupancy, out-of-pocket cost, access shares and distance, wait time).

Major Outputs: Transportation benefits and costs, emissions (not including CO_2), energy consumption.

Overview of Calculations: The model takes into account congestion-related effects of changes in VMT on speeds during peak and off-peak periods, diversion of traffic among parallel highway facilities in a corridor, induced (or suppressed) traffic occurring as a result of changes in highway congestion levels, and effects of speed and cold starts on motor vehicle emissions and fuel consumption. Fuel consumption is based on a table of fuel consumption rates by speed.

Scope:

- Temporal – Not specified.
- Geographic – Corridor or system level (nonspatial).
- Modal, Vehicle, Fuel – Highway vehicles and transit; no fuel segmentation.

Strengths and Weaknesses for Travel Reduction/Efficient Driving Analysis:

- Strengths – The model has some unique features, including accounting for traffic diversion, induced demand, and speed changes at a sketch-planning level.
- Weaknesses – The model is primarily suited for broad-scale cost/benefit analysis of modal alternatives and strategies at a corridor level. The fuel efficiency factors (and other factors) in the model may not be up-to-date, but can be adjusted by the user.

Resources:

- Cambridge Systematics. "Sketch-Planning Analysis Spreadsheet Model User's Guide." Prepared for FHWA (U.S. DOT 1998).
- FHWA website (U.S. DOT 1998a).

3.2.3.5. Elasticities

Overview: Elasticities are a measure of the percent change in the quantity demanded of some good caused by a percent change in its price. They are frequently used for sketch-level analysis of changes in travel alternatives that can be quantified, including changes in time, cost, and amount of service provided. For example, transit ridership elasticities can be used to estimate response to changes in quantifiable service parameters, such as service frequency, route travel time, and fare levels. Elasticities have also been used to measure response to road pricing, parking pricing, bicycle infrastructure provision (e.g., miles of bicycle lane per square mile), pedestrian improvements (measured through a diversity or design index), and other pricing and modal improvement strategies.

Developer/Owner: Elasticities are a concept that originated in the field of economics. Numerous studies have documented elasticities relevant to travel analysis.

Examples of Specific Models: Elasticities are embedded in numerous travel analysis models as well as being used on a stand-alone basis.

Extent of Use: Widely used.

Intellectual Property Rights and Transparency: N/A.

Major Inputs: Elasticities are derived from data on traveler response and changes in underlying factors. They are often derived from multivariate statistical models, isolated at fixed levels of other variables in the model.

Major Outputs: Change in travel quantity (i.e., mode use, trips, VMT).

Overview of Calculations:

Scope:

- Temporal – “Short-run” and “long-run” elasticities are often distinguished, where short-run elasticities reflect changes that travelers can make immediately or in the near term (one to five years) and long-run elasticities reflect changes that take place over a longer time period, such as changing residence or workplace location.
- Geographic – One limitation with elasticities is that they may be valid only in specific contexts (i.e., geographic, temporal) for which they were developed. Traveler response may differ in situations in which other controlling factors (not reflected in the simple elasticity relationship) are different. “Transferability” should be validated through studies in different geographic contexts.
- Modal, Vehicle, Fuel – Elasticities have been applied both within mode and cross-mode (e.g., transit ridership response to automobile fuel price changes). They can be applied to model vehicle and fuel choice (e.g., elasticity of fuel economy with respect to fuel price).

Strengths and Weaknesses:

- Strengths – Widely available and widely applied for quantitative factors, especially changes in time and cost.
- Weaknesses – Simple one-to-one relationship ignores other controlling factors. Sometimes applied where they are not valid (out of range or out of context).

Resources:

- The publications *Transit Cooperative Research Program (TCRP) Report 95: Traveler Response to Transportation System Changes* (TRB 2011c) and Litman’s *On-Line TDM Encyclopedia* (VTPI 2011b) report elasticities from the literature on a variety of issues related to transit, ridesharing, and nonmotorized travel.

3.2.4. Emission Factor Models

3.2.4.1. MOBILE6, MOVES, and EMFAC

Overview: These models are used to develop emission factors (e.g., GHG emissions per mile traveled) for motor vehicles. They provide an alternative to the use of aggregate average factors based on fleet-average fuel economy and fuel carbon content. These models are primarily designed for air quality analysis but are increasingly being used for GHG and energy analysis as well.

Developer/Owner: EPA, California Air Resources Board.

Examples of Specific Models: The EPA's current on-road emission factor model, MOVES, supersedes the MOBILE series of models (most recently MOBILE6). In California, EMFAC, developed by the California Air Resources Board, is used.

Extent of Use: MOBILE6 and MOVES are widely used by regional and state agencies in areas that are not in attainment of national ambient air quality standards. MOVES will be the required model for regional air quality conformity analysis (in states except California) as of March 2013. EMFAC is used by agencies throughout California.

Intellectual Property Rights and Transparency: Public domain.

Major Inputs: Vehicle fleet characteristics (i.e., vehicle age distributions, VMT by vehicle type), travel speeds, climate, local fuel characteristics, emission control programs.

Major Outputs: Emission factors—typically expressed in grams per vehicle-mile—for GHG that include CO_2, methane, nitrogen dioxide and total carbon dioxide equivalent (CO_2e).

Overview of Calculations:

Scope:

- Temporal – MOVES: Any year through 2050.
- Geographic – Uses national default inputs or region-specific inputs. MOVES is pre-populated with county-level default data.
- Modal, Vehicle, Fuel – All light- and heavy-duty on-road vehicles; multiple vehicle types (based on weight and fuel type); gasoline, diesel, and compressed natural gas (MOVES only).

Strengths and Weaknesses:

- Strengths – Models are updated to reflect adopted federal and California fuel efficiency/GHG emissions regulations; therefore, they provide the most up-to-date estimates of future, as well as current emissions. They can provide speed-based emission factors that can be used to assess how fuel consumption/emissions vary by level of congestion as well as overall VMT. When used with local input data, they reflect factors that may cause fuel economy and GHG emissions to vary from area to area, including the age and composition of the vehicle fleet, as well as fuel characteristics (e.g., 100% gasoline versus ethanol blend). MOVES can also be used in project-level mode to incorporate detailed vehicle operating characteristics (e.g., accelerations, queuing). These models provide more accurate estimates of methane and nitrogen dioxide emissions than simply using default factors from a literature source.
- Weaknesses – These models are not stand-alone methods for predicting the energy and GHG impacts of travel reduction and efficient driving strategies, but instead must be used in conjunction with methods that predict changes in travel behavior. They require some expertise to use, as well as some effort to collect and develop local inputs if this has not already been done by an agency for air-quality modeling purposes. MOVES can be run using default data, but the advantages of using specific local data are not gained.

Resources:

- EPA MOVES model and guidance (MOVES 2012).
- EMFAC software (EMFAC 2011).
- EPA (2012). *Using MOVES for Estimating State and Local Inventories of On-Road Greenhouse Gas Emissions and Energy Consumption: Public Draft*. EPA-420-D-12-001.

4. Review of Individual Strategies

This section reviews each of the strategies listed in Table 1.1. These were selected based on authors' judgment and in consultation with stakeholders to identify travel reduction and efficient driving strategies with the greatest potential interest in targeting GHG emission and petroleum use reductions. This section includes information about strategies outlined in existing literature, as well as assessments and information based on Cambridge Systematics' judgment and unpublished knowledge of the field. The purpose of this section is not to recommend implementation of any particular strategy or set of strategies, but to summarize quantitative studies of their effects, where such evidence exists, as well as to outline qualitative assessments.

4.1. Pricing

Description of Strategy. Pricing strategies increase the marginal cost per mile driven, providing a greater incentive to reduce travel, and resulting in fewer trips, shorter trips, greater use of alternative modes, and travel shifts to periods of lower congestion. The specific impacts depend on the alternatives available to travelers (i.e., mode, destination) and price sensitivity, which varies by income, personal and household characteristics, and characteristics of the specific trip.

Pricing can take a number of forms, including:

- VMT fees (charging drivers per mile of travel)
- Increases in the existing gasoline tax or new fuel or carbon taxes that price travel according to fuel consumed or carbon emitted (providing an incentive to purchase more efficient vehicles as well as to reduce travel)
- Facility-specific tolls
- Congestion pricing (pricing roadway facilities when they are congested to reduce traffic on those facilities to an improved level of service)
- Cordon/area pricing (applying a fee for vehicles to enter or operate within a selected area, such as a central business district)
- PAYD insurance (converting a significant portion of the essentially fixed cost of insurance to a marginal cost based on mileage).

Energy and GHG Impacts. Price impacts are frequently measured using the concept of elasticities, such as the elasticity of VMT with respect to fuel price.[4] There is an extensive body of literature on elasticities for travel costs, largely focused on responses to changes in motor fuel prices. Small and van Dender (2007) estimate long-run price elasticities of VMT were -0.210 between 1960 and 2004 (i.e., a 10% increase in price leads to a 2.1% decrease in VMT), but only -0.057 for the most recent period of 2000 to 2004, suggesting that elasticities have declined over time. Litman (2011), however, suggests that elasticities

[4] The same elasticity is generally assumed regardless of the baseline price. The assumption of constant elasticities is simplistic, however, and may not correctly represent traveler response to price changes at different levels. For example, Gregor (2010) postulates—and finds supporting evidence in Consumer Expenditure Survey data—that households have a fixed transportation budget and modest price increases up to a certain level will result in substitution within the transportation category (e.g., reducing spending on new vehicle purchases) rather than reducing travel. A pilot study of mileage-based fees in Minnesota (Buxbaum 2006) provided evidence contrary to this point by finding evidence that some households are willing to change their behavior even at relatively low-fee levels and that further increases in fees (above $0.05 a mile) had little additional impact on travel because other households are unwilling or unable to change their behavior (Buxbaum 2006).

may be increasing again, implying that elasticities may change as fuel prices and economic conditions change.[5]

A key point from Small and van Dender is that price elasticity declines with rising income and also declines with rising fuel efficiency. The underlying insight is that elasticity is higher when driving costs are a large share of income and lower when driving costs are a small share of income. This insight is of particular importance in a world where incomes are growing, fuel efficiency is improving due to regulation, and petroleum prices are remaining approximately stable. In this environment, we can expect price elasticity to decline over time, requiring an ever-larger price signal to produce an equivalent effect.

Using elasticities from the literature, U.S. DOT (2010c) estimated that a toll of \$0.02 per mile (roughly equivalent to current motor fuel taxes, or about \$0.50 for the average round-trip commute of 25 miles) would reduce VMT by about 1%, with a corresponding reduction in GHG emissions from motor vehicles. A higher toll of \$0.05 per mile —in the range of PAYD insurance—would reduce VMT by about 2.5%.

Impacts of other types of fees would be similar. For example, a carbon price of \$30 per tonne would increase the price of gasoline by \$0.26 per gallon, equivalent to just over \$0.01 per mile at the current light-duty fleet average fuel economy of about 20 miles per gallon. However, the price impact per mile would decrease as fuel efficiency increases and as lower-carbon fuels are used, meaning that VMT impacts of the same carbon fee would become smaller as new, more efficient vehicles enter the fleet.

Impacts of congestion pricing may vary substantially depending on the spatial and temporal extent of the pricing. A study for the DOE extrapolating results from Minneapolis–Saint Paul and Seattle travel demand models to the entire United States estimated that congestion pricing could reduce national fuel consumption and GHG emissions from highway travel by 0.5% to 1.1% (National Energy Technology Laboratory 2008). Cordon pricing has not been applied in the United States, but Cambridge Systematics (Urban Land Institute 2009) estimated that the application of cordon pricing to all central business districts nationwide would affect only 3% of urban VMT (about one-tenth the effect of system-wide congestion pricing), leading to small fuel and GHG reductions.

The impacts of pricing will also vary depending on the alternatives available to drivers, which will vary by regions of the country, sub-locations within a metropolitan area, and by time of day and trip purpose. For example, Guo et al. (2011), examining data from a mileage-based fee experiment in Portland, concluded that when the travel cost increases in peak hours, households living in denser and mixed-use neighborhoods are able to reduce their VMT more than those living in other types of neighborhoods.

In addition, if not well designed, pricing strategies can have unintended negative effects, such as traffic diversion that increases VMT or congestion. For example, based on transportation planning experience, applying tolls to a single freeway may divert traffic to parallel arterials. Cordon pricing may lead to increased travel outside the priced area. Even if total VMT is reduced, added congestion on the alternative facilities may lead to offsetting increases in GHG emissions.

[5] Care is required in applying elasticity values to changes in costs. The value of the elasticity will be different depending on whether the change in travel cost is measured relative to just one component of travel (e.g., fuel price) or relative to the full cost of travel (including vehicle operating costs, user-borne crash costs, and time savings). For a full discussion of this issue, see U.S. DOT (2010c).

Key Uncertainties.

Policy Factors	Technology/Science Factors
Political capability to implement any form of price increase. Level of price set/price change. Willingness of consumers and insurance industry to accept mandatory versus voluntary PAYD.	Potential nonlinearities and geographic variations in response to price changes. For strategies with limited temporal and spatial applicability, extent to which travel is shifted to other locations and time periods versus reduced.

Other Benefits and Impacts.

- Mobility – Fees that increase the average cost of transportation will lead to some welfare losses as a result of decreased mobility. To the extent that congestion is reduced, however (particularly with congestion pricing), some peak-period travelers with high values of time (or those riding transit and not paying fees) will benefit.
- Revenues – Fees will also generate public-sector revenue. A $0.05 per-mile VMT fee would generate over $150 billion per year, growing annually. Some of these costs would be needed to cover administration of the fee, but the remainder could be reinvested in infrastructure or returned to taxpayers.
- Equity – Pricing may have negative or positive equity implications depending on how it is applied and what alternatives are available to travelers. For example, congestion pricing will benefit higher-income travelers, who are likely to place a greater monetary value on saving time. On the other hand, by shifting more of insurance costs onto high-mileage drivers, PAYD may benefit lower-income drivers, who tend to be lower-mileage drivers.
- Air Pollution – While all pricing will reduce air pollutant emissions in proportion to VMT reductions, congestion and cordon pricing may have disproportionate benefits, because emissions are generally higher in congested conditions.

Costs. Some pricing programs require monitoring technology to determine how much each vehicle will be charged, and a mechanism for collecting fees. The major costs of these programs arise from purchase, installation, maintenance, and replacement of the monitoring technology, and administrative costs of fee collection. Pricing programs that rely only on fuel quantity purchased require no additional technology and so are least costly. Pricing programs that rely on VMT (VMT fees, PAYD, and system-wide congestion pricing) can base charges on data from lower-cost but less accurate mechanical odometers attached to wheel hubs, or more accurate, more expensive electronic systems. U.S. DOT (2010c) estimated the nationwide implementation of VMT fees to cost $131 billion cumulatively through 2050 using mechanical odometers attached to wheel hubs. More effective electronic systems are estimated to cost $230 billion over the same time period. It is likely that costs will come down as technology advances. Costs for PAYD and system-wide congestion pricing technology using the same monitoring methods would be similar. Pricing programs that rely on determining use of specific zones or corridors (cordon pricing, corridor congestion pricing) base charges on technology that tallies vehicle presence within the zone or corridor. Cambridge Systematics, Inc. (Urban Land Institute 2009) and U.S. DOT (2010c) include cost-effectiveness estimates and related data: VMT fees and PAYD insurance were found to deliver a moderate to good return on investment ($30 to $150 per tonne GHG reduced based on direct implementation costs), while cordon pricing and congestion pricing systems were less cost-effective at a cost of $300 to $700 per tonne of GHG reduction because they had a similar level of cost but less effect.[6]

[6] All cost-effectiveness estimates presented in this report reflect implementation costs only and do not include cost increases or savings to users or other social costs and benefits. For example, efficient levels of congestion pricing can produce significant economic benefits by internalizing the external costs of congestion. Cambridge Systematics, Inc. (Urban Land Institute 2009)—

Interactions. Pricing is likely to be more effective in areas where travelers have better alternatives (transit, nonmotorized, etc.) Pricing may also support these options and make them more attractive. However, the interactions among pricing, transit, land use, TDM, and other strategies have not been well quantified.

Development Status. The simplest administration of pricing is through the existing fuel tax. Congestion pricing and tolling have been implemented at a facility level, but not area wide in the United States; the technology exists, but full deployment would be fairly expensive. Cordon pricing has been implemented in a few cities internationally using different mechanisms. PAYD has been pilot-tested in a few states, using both self-reporting mechanisms and global positioning systems (GPS).

Implementation. Fuel taxes are currently administered at both state and federal levels. A VMT fee could be administered at either level, as well. Congestion pricing could be implemented by states or MPOs. Cordon pricing has been implemented or studied by municipalities, but could also be implemented by MPOs. PAYD is implemented by private insurance providers, but enabling legislation and/or incentives may be required in some states (the insurance industry is regulated at a state level).

Barriers. Political barriers are currently the strongest impediments to any form of pricing that increases the cost of travel. Privacy issues related to monitoring travel also need to be addressed. Pricing is more likely to be accepted if it is optional (e.g., optional PAYD, HOV/toll lanes). The private sector has shown some interest in voluntary PAYD insurance, but to maximize effectiveness, it would likely need to be made mandatory, requiring federal and/or state legislative action.

4.2. Transit Improvements

Description of Strategy. Transit improvements include system expansion, service promotion, and service improvements, such as:

- Investing in new fixed-guideway urban transit, including light rail, heavy rail commuter, rail, streetcars, or bus rapid transit
- Expanding coverage of bus systems
- Increasing the frequency and/or time coverage of service on existing routes
- Reducing fares
- Making other improvements to the quality of service on urban transit systems.

Intercity bus and rail improvements may take the form of expanded or enhanced service on existing bus or rail routes, new intercity bus or rail routes, and high-speed rail. Improvements to intermodal facilities and information help minimize travelers' time, costs, and inconvenience, and make it easier for people to utilize the most efficient mode for each segment of a trip.

Energy and GHG Impacts. Transit systems have the potential to reduce fuel consumption and GHG emissions through both direct emission benefits per passenger-mile of transit versus automobiles, and the additional indirect effect on emissions that transit provides through its impact on land-use patterns. The magnitude of the benefit depends on the relative efficiency of transit vehicles and automobiles (which may change in the future), as well as loading factors (persons per vehicle). Based on 2009 data, the Federal Transit Administration (FTA) calculates that bus transit averaged 0.65 pound of CO_2e per passenger-mile, compared to 0.41 for light rail, 0.35 for commuter rail, and 0.24 for heavy rail, calculated at average occupancy levels across all systems in the United States. This translates into an overall average of 0.48 pound CO_2e for all urban transit systems (except demand-responsive systems). These figures compare to 0.96 pound of CO_2e per passenger-mile for single-occupant passenger vehicles and 0.62

the source of many of the cost-effectiveness estimates cited here—estimated both direct implementation costs and vehicle operating cost savings (primarily fuel) for a range of GHG reduction strategies; however, other benefits and costs, such as mobility, were not estimated due to the difficulty of measuring and monetizing them.

pound of CO_2e per passenger-mile for passenger vehicles at average occupancies of 1.63 persons per vehicle (U.S. DOT 2010c). The results are heavily influenced, however, by a few large cities with large, high-volume transit systems. A U.S. PIRG study found that 26 states saw very small reductions or even slight increases in GHG from their transit services (Baxandall, Dutzik, and Hoen 2008). In many U.S. cities, rail systems have higher average energy use per passenger-mile than personal vehicles (O'Toole 2008).

Cambridge Systematics (Urban Land Institute 2009) estimated that urbanized transit systems in 2007 removed 32.0 billion VMT from the nation's roadways, representing 1.6% of urban area VMT. The net effect is a reduction of 14 million metric tons (mmt) of GHG emissions. The net GHG effect of future transit improvements will depend on factors including new ridership attracted from automobiles, number of passengers per transit vehicle, relative efficiency of transit vehicles and automobiles, and carbon content of fuels. Based on Cambridge Systematics (Urban Land Institute 2009), U.S. DOT (2010c) estimated that different scenarios of service and ridership growth could result in savings of 0.4% to 1.1% of on-road vehicle emissions in 2030, or 0.6% to 2.0% in 2050.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Fiscal and political capacity to support major transit service increases.	Extent to which service expansion can be accomplished while also increasing system-wide transit load factors as a function of a) cost of vehicle-travel, and b) transit-supportive land-use patterns.
Relative efficiency of future transit versus highway vehicles (compared to current technology).	
GHG intensity of the future electricity grid.[a]	

[a] *These factors could be strongly affected by both policy initiatives and technological advancement.*

Other Benefits and Impacts. A significant benefit associated with transit is its ability to level the transportation playing field for those who choose not to drive or do not own vehicles. Transit increases accessibility to economic and social opportunities and helps physically and economically disadvantaged people access public services, education, and employment.

Transit will result in reductions of some criteria pollutant emissions, but may cause increases in others, especially oxides of nitrogen and particulate matter, depending on technology (e.g., diesel versus electric) and load factors.

Costs. Expansion of transit infrastructure and/or service requires significant capital and operating investment. In a 2008 report to Congress, the National Surface Transportation Policy and Revenue Study Commission estimated baseline transit investment needs to be $1.1 trillion through 2020, $2.4 trillion through 2035, and $4.4 trillion through 2055, in order to realize an annual transit travel growth rate of 1.57% (National Surface Transportation Policy and Revenue Study Commission 2007). Transit has not been found to be a cost-effective strategy when evaluated solely on an energy use or pollution reduction basis. Even while Cambridge Systematics (Urban Land Institute 2009) found costs in excess of $1,000 per tonne of GHG for most transit improvement strategies, Schipper (2009) concluded that the CO_2 reduction benefits of transit represent only a small fraction of the net social benefits and recommended that decisions be based on a much broader range of criteria, including mobility, safety, and air quality.

Interactions. The effectiveness of transit as an energy and GHG reduction strategy may be increased by planning transit services in coordination with supportive land-use patterns. Dense, mixed-use, and pedestrian-friendly development supports transit ridership by allowing more travelers to directly and conveniently access transit, reducing the relative attractiveness of automobile versus transit travel. Fixed-guideway transit investments (such as rail or bus rapid transit) can also reinforce supportive land-use patterns by encouraging higher-density development. The greatest benefits will be realized through transit-supportive land-use patterns at both the origin and destination end of the trip. Pricing of roadway travel and parking also provide greater incentives to use alternative modes, including transit. Transit improvements in low-density areas, or in locations with few traffic congestion problems and inexpensive parking, may not lead to net energy and GHG benefits, because the improvements may not attract sufficient ridership to offset the additional transit vehicle emissions.

Development Status. Most large- and medium-sized cities currently operate bus systems. A growing number are developing rail systems, especially light rail, commuter rail, and streetcars. The most extensive rail infrastructure is found in large cities, and encompasses older systems (New York, Boston, Philadelphia) as well as newer systems (Atlanta, Los Angeles, San Francisco, Washington, D.C.). Bus rapid transit has been promoted by the FTA and some advocacy groups as providing less costly, and more cost-effective, improvements than new rail service in some situations (U.S. DOT FTA), and new bus rapid transit lines have been built in cities including Boston, Cleveland, and Eugene-Springfield, Oregon.

Implementation. Transit systems are owned and operated by local or state public transit agencies. Although some transit expansion initiatives have been funded through local sources, in most areas significant expansion beyond current levels could require significant additional federal investment.

Barriers. Funding is not the only barrier to transit expansion. Most U.S. urban areas are low density, which is not conducive to transit services. In regions with minimal congestion challenges and low-cost parking, transit is simply not competitive with the automobile (in travel time or cost), and it is difficult to achieve load factors that are high enough to provide net energy or emissions benefits.

4.3. Nonmotorized Improvements

Description of Strategy. Nonmotorized transportation strategies seek to make walking, bicycling, and other nonmotorized modes more attractive and competitive with automobile travel, including:

- Infrastructure improvements, such as sidewalks, pedestrian crossings, traffic calming, on-street bicycle lanes, and off-street/shared-use paths
- Destination-based facilities, including secure bicycle parking and lockers and showers for changing
- Land-use policies to promote pedestrian-friendly site design
- Information and education, such as wayfinding, bicyclist training, and other safety-focused programs.

Nonmotorized transportation is sometimes known as “active” transportation because it involves physical activity.

Energy and GHG Impacts. Pedestrian improvements are likely to have only minor impacts unless they are implemented in conjunction with land-use strategies to promote compact, mixed-use development. The primary factor in choosing to walk is the distance to the destination, with walk trips averaging only 0.7 miles (U.S. DOT 2010c). Nevertheless, pedestrian improvements can help to reduce VMT and GHG, especially in areas where destinations are relatively close together, but wide streets or a lack of sidewalks and safe crossings discourage pedestrian activity. Bicycle trips are longer (nearly 3 miles on average), but are still most competitive in areas where automobile travel is relatively slow (due to traffic congestion) and/or expensive (due to high fuel and/or parking prices).

Cambridge Systematics (Urban Land Institute 2009) estimated the potential benefits of comprehensive programs of bicycle and pedestrian improvements implemented between 2010 and 2025 in all U.S. metropolitan areas. Pedestrian improvements focused in areas of higher population density, as well as around schools, business districts, and transit stations, were estimated to reduce on-road GHG emissions by about 0.15% to 0.4% in 2030. Bicycle improvements were estimated to reduce emissions by about the same amount, based in part on experience in European cities. The combined impact of pedestrian and cycling improvements was 0.3% to 0.8% of on-road vehicle emissions. Because of the limited evidence on pedestrian and bicyclist response to such improvements, however, there is considerable uncertainty in these estimates. The GHG benefits of nonmotorized investment should increase over time, as facilities are deployed.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Ability of cities throughout the United States to implement pedestrian and bicycle improvements similar to leading cities (e.g., Portland).	Extent to which mode shifts consistent with leading cities can be achieved throughout the United States. Extent to which a) travel prices and b) cultural shifts may increase interest in nonmotorized modes over time.

Other Benefits and Impacts. Nonmotorized improvements provide increased opportunities for recreational activity, as well as transportation options, increasing physical activity and improving public health. Bicycle and pedestrian strategies can improve mobility by providing people with increased travel options at a lower cost. Bicycle and pedestrian improvements and programs should also increase safety for nonmotorized travelers.

Costs. Pedestrian and bicycle enhancements can be implemented at lower cost in new developments, e.g., by integrating facilities into the design of streets and building sites. Retrofitting existing developments and roadways may, in some cases, incur higher costs because of right-of-way or other constraints. A review of comprehensive bicycle plans in five large U.S. and Canadian cities found total implementation costs range from $70 to $240 million over a 10- to 20-year period, with an average cost of $211 per person. Pedestrian plans in four cities were on the same order of magnitude (U.S. DOT 2010c). Three hypothetical scenarios of nationwide pedestrian improvements were estimated to cost between $20 and $55 billion over a 15-year period, with three scenarios of bicycle improvements costing between $6 and $59 billion (Urban Land Institute 2009). Cost-effectiveness was judged to be moderate ($80 to $210 per tonne), considering only direct implementation costs and no other social benefits, such as mobility improvements.

Interactions. As discussed, compact land use is a prerequisite to high levels of walking and bicycling. Therefore, the effectiveness of strategies to improve walking and bicycling infrastructure will vary greatly depending on the geographic context. Vehicular pricing (especially parking) and the availability of complementary transit services will also influence nonmotorized travel. Climate and topography may affect people's propensity to travel by nonmotorized modes and limit most travel shifts to times of the year when the weather is more favorable.

Development Status. Most older cities have fairly well-developed sidewalk systems and new development and roadway improvements across the country typically include pedestrian facilities as standard practice. A growing number of states and municipalities are also adopting "complete streets" policies and practices that accommodate pedestrians and bicycles. Some cities are aggressively implementing bicycle infrastructure improvements, such as systems of lanes and parking.

Implementation. Bicycle and pedestrian improvements, including relevant roadway design standards, are implemented by municipalities for local streets and state DOTs for state-owned roadways. (The balance of authority over roads between municipalities and states varies widely from state to state.) MPOs and DOTs may develop bicycle and pedestrian plans for a region or state, including general policies, major facility priorities, and funding programs. MPOs and state DOTs also play a role in allocating funding and selecting projects, which may include stand-alone bicycle/pedestrian projects, such as shared-use paths, or criteria for bicycle and pedestrian accommodations in roadway design. The federal government may set aside funding for specific purposes and/or require or encourage specific design considerations to be followed. The Congestion Mitigation and Air Quality Improvement (CMAQ), Transportation

Enhancements, and Recreational Trails programs are federal funding sources commonly used for bicycle and pedestrian improvements.[7]

Barriers. Based on Cambridge Systematics' assessments and interactions with the transportation community, pedestrian improvements are considered popular in many cities, and the benefit of pedestrian-supportive design is gaining fairly wide acceptance. Widespread implementation of such improvements, however, can be a challenge for financially strapped municipalities. Bicycle improvements are also thought to be gaining in popularity, but face political, institutional, and technical challenges, especially when they require compromises in traditional roadway designs. The extent to which people will be willing to walk or bicycle for transportation is limited by practical constraints (e.g., need to carry packages, transport children, travel long distances, weather issues), as well as cultural factors.

4.4. Parking Management

Description of Strategy. Parking management involves changes to parking supply, pricing, or other management techniques to create disincentives to driving. Examples include: reducing parking requirements for new development; designing and locating parking to encourage pedestrian travel for short local trips; charging workers for parking or allowing them to "cash out" the value of parking if they do not use it; "unbundling" residential parking costs from the cost of a lease or purchase; pricing to encourage "park-once" behavior; pricing to maintain vacant spaces to reduce parking search time; and using information technology to help drivers efficiently locate spaces.

Energy and GHG Impacts. Both the cost and supply of parking are significant determinants of travel behavior. These factors tend to be closely related, as parking tends to be priced when—and only when—its availability is limited.

Information on the potential nationwide GHG reductions from parking pricing or other parking management strategies is very limited. According to U.S. DOT (2010c), nationwide, only 5% of employees pay for parking, so, in theory, there is great potential for expanding the scope of worksite-based parking pricing. On the other hand, market prices for parking usually exist only in central business districts and other densely built activity centers and, according to data from the 2000 U.S. Census, less than 10% of a typical metropolitan area's workforce is located in the central business district. A DOE study estimated that if an additional 5% of workers nationwide could have parking priced at market rates, reducing single-occupancy vehicle (SOV) use per worker by 20%, and further and considering that work trips make up 30% of total VMT, the total reduction in VMT on a nationwide basis would be approximately 0.3% (National Energy Technology Laboratory 2008). A nationwide fee of $5 daily per parking space levied on all worker-utilized parking spaces is estimated to reduce VMT and emissions much more substantially —by nearly 2.5% (Urban Land Institute 2009). It is not clear how such a broad-based fee would be implemented or enforced. Furthermore, a risk associated with constraining or pricing the supply of parking in limited geographical areas is that activity will shift toward areas in which parking is not constrained, offsetting the benefits.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Extent to which the public and officials will change their views of parking pricing, which has been unpopular.	Extent to which pricing implemented on a limited geographic basis will simply shift trips to other locations rather than reduce vehicle trips.

[7] The Moving Ahead for Progress in the 21st Century Act (MAP-21) of 2012 eliminates Transportation Enhancements and Recreational Trails as separate programs but makes the same project types eligible under an umbrella Transportation Alternatives program.

Other Benefits and Impacts. Depending on how they are implemented, parking strategies may lead to improvements or declines in mobility for specific segments of the traveling public. For example, reducing the land devoted to parking will make areas more pedestrian friendly, supporting pedestrian and transit mobility; but vehicular mobility will be reduced if parking is made more costly or scarce.

Costs. Some parking management strategies, such as changes to minimum and maximum parking requirements, can be implemented with minimal administrative cost. Parking management can actually result in cost savings to developers and tenants, especially in areas of high land value, as the cost of structured parking typically ranges between $15,000 and $30,000 per space. Pricing of parking that was previously free requires the establishment of a system for monitoring parking and collecting revenues. Based on Cambridge Systematics' review, the administrative costs of parking pricing implemented on a widespread basis have not been estimated.

Interactions. Achieving the full benefits of parking management will be strongly dependent on land-use strategies to develop high-density activity centers, creating higher land values that support a market for parking and supporting travel alternatives.

Development Status. Parking is typically priced only in limited places where there is a market for it (central business districts and other major activity centers). Examples of businesses offering cash-out or residential developers unbundling parking costs are relatively rare. A few jurisdictions have implemented reductions in parking requirements in areas served by transit or core central city neighborhoods. An even smaller number have moved toward active management of on-street parking through pricing that changes based on demand, with San Francisco being a notable example.

Implementation. Most parking management strategies are within the domain of local government, through land-use regulations (requirements for new development) and management of on-street parking supply. Parking cash-out, worksite parking pricing, and unbundling parking can be implemented by employers or property managers.

A current federal policy allows employers to provide parking as a qualified tax-free fringe benefit to employees. Section 132(f)(2)(B) of the Internal Revenue Code allows a fringe benefit exclusion for qualified parking of up to $240 per month in 2012. This compares with the 2012 fringe benefit limit of $125 per month for transit and vanpools (National Center for Transportation Research 2012). Taxing these parking benefits would reduce the incentive for employers to provide free or discounted parking.

Other potential roles of the federal government in encouraging parking management have not been investigated. A broader set of incentives (including, for example, federal transportation funding) could perhaps be provided to encourage local governments to implement "compact development" land-use strategies aimed at reducing vehicle travel and facilitating alternative mode use. It is also conceivable that the federal government could implement a tax on parking spaces, but this would be a major change in U.S. tax policy, which typically leaves property taxes to the local government.

Barriers. Managing demand via parking policies has met considerable political resistance in most locations. Key barriers include local opposition to reductions in parking requirements for new development for fear of competition for parking spaces or "overflow" parking in neighborhoods, and resistance to any efforts to price or increase the cost of parking. Employers often view free parking as an important benefit for attracting and retaining employees.

4.5. Worksite Trip Reduction/Employee Commute Options

Description of Strategy. Efforts to reduce SOV commute trips have long been a staple of TDM. Commute-focused trip reduction initiatives have included alternative mode information, transit subsidies, ridesharing/ridematching programs and incentives, vanpools, parking management strategies (including pricing and cash-out), and telework and alternative work schedule (AWS) options. Worksite trip reduction programs may include either requirements for employers to reduce SOV trips by their employees or outreach, assistance, and incentive programs to encourage them to do so.

Energy and GHG Impacts. Of the various worksite-based strategies, financial incentives and disincentives, such as free or discounted transit passes, parking pricing, and cash-out, generally have greater impact than information and coordination services (COMSIS Corp. and Institute of Transportation Engineers 1993; VTPI 2010a).

The impacts of worksite-based TDM programs have generally been modest, although not negligible. One review of the literature on commute-focused TDM programs concluded that an overall *area-wide* reduction in SOV work trip mode share on the order of 5% may be realistic, which translates into net regional VMT impacts of around 1% (U.S. DOT 1999a). A recent report for the DOE (National Energy Technology Laboratory 2008) estimated an outreach and incentive program aimed at all metropolitan workforces nationwide could reduce total U.S. VMT by 0.2% to 1.1%. Cambridge Systematics (Urban Land Institute 2009) estimated that a nationwide voluntary outreach program targeting employers, paired with regional support services, could reduce emissions by 0.4% in 2030, while a program that included trip reduction requirements for employers with at least 50 employees (coupled with regional support services) could reduce GHG by 0.9%.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Ability to implement widespread TDM requirements or incentive-based programs in cities throughout the United States.	Extent to which TDM strategies can show significant impacts in smaller- to medium-sized cities with limited travel options.

Other Benefits and Impacts. To the extent that TDM programs are voluntary for employees, they can improve mobility by expanding travel options or provide information regarding options. Lower income travelers may benefit the most from subsidies or lower cost options. In theory, mandatory TDM requirements could restrain mobility (e.g., parking restrictions that require some employees not to drive), but few programs have taken such a restrictive approach. Worksite TDM can help reduce congestion by focusing on removing trips from the most congested peak-hour times and employment center locations.

Costs. The costs of demand management strategies include administrative expenses to coordinate programs, which are borne by employers and local or regional agencies, as well as capital costs for equipment for telecommuting equipment or vanpooling. Major state and regional TDM programs typically employ 5 to 10 full-time staff equivalents, with program expenses of up to a few million dollars a year. Subsidies or incentives for alternative modes (e.g., transit passes, vanpools) are transfer payments rather than net social costs, but nonetheless are public-sector expenses. U.S. DOT (2010c) judged the cost-effectiveness of worksite-based TDM to be moderate to high ($30 to $180 per tonne CO_2e).

Interactions. The extent to which individuals are willing to shift modes will be affected by other factors, such as fuel prices and the quality of alternatives provided. The effectiveness of trip reduction measures depends in part on future land-use patterns, transit investments, and/or pricing policies that support the use of alternative travel modes.

Development Status. Employer trip reduction requirements exist in Oregon and Washington states and in the Phoenix and Tucson, Arizona, metropolitan areas. They were introduced in Southern California in the early 1990s, but were later rescinded. A few cities and counties also require employers to reduce trips or implement TDM programs. A number of state, regional, and local transportation agencies coordinate voluntary demand management programs. The federal government has had some involvement, including allowing up to $230 per year in tax-free transit and vanpool benefits. The EPA's Best Workplaces for Commuters program (2001–2007) provided assistance and recognition to employers offering commute benefits. Some state and regional TDM programs have been funded using federal transportation funds for congestion mitigation and air quality improvement.

Implementation. Worksite-focused TDM programs are coordinated by states, MPOs, and local governments. Individual employers and property owners have sometimes formed associations to implement TDM, mostly in areas with substantial traffic problems. In general, the role of the federal government has been focused on funding for air quality programs, information and technical assistance, and tax incentives.

Barriers. The primary barriers to worksite trip reduction are 1) developing and adopting programs that are both politically acceptable and effective; 2) ensuring that information and incentives reach individual travelers; and 3) factors such as transit availability, work schedules, and personal preferences, that make it difficult for individuals to switch modes. Requirements-based strategies, such as trip reduction ordinances, generally reach a broader base of employers than voluntary- and incentive-based demand management strategies, but are politically more difficult to implement. States and local jurisdictions that have adopted trip reduction requirements have typically not assessed penalties for failing to meet targets.

4.6. Telework and Alternative Work Schedules

Description of Strategy. Teleworking or telecommuting employees use telecommunications and computer technology to work from locations other than a traditional office. Compressed work weeks fit a regularly scheduled number of hours in a shortened span of time (e.g., 80 hours in nine days). Flexible work schedules provide alternatives to a standard 9:00 a.m. to 5:00 p.m. work schedule for commuting employees.

Energy and GHG Impacts. The ability to telework or adopt AWS depends on the type of job, whether the location and timing of the work is flexible or rigid, as well as employer and employee personal preferences.

U.S. DOT (2010c) attributes approximately 28.9 billion VMT and 10 to 13 mmt CO_2e of 2008 emission reductions to teleworking. This estimate assumes a telecommuting rate of between 12% and 15% of employed workers and an average frequency of 1.5 days per week. National survey data, as well as surveys in Phoenix, Arizona, and metropolitan Washington, D.C., suggest that telework has the potential to approximately double compared to current levels. If this were the case, the potential GHG benefits from additional teleworking would be about 0.6% to 0.8% of on-road transportation emissions. These estimates assume a short-term “rebound” effect of about 25%, because workers make trips from home on telework days that were previously chained with work trips. There may be additional offsetting emissions from increased home energy use (perhaps 11% to 25% of the travel energy savings) and long-term relocation effects as workers choose more remote locations.

Compressed work weeks should provide similar travel benefits to telecommuting per avoided commute trip; however, only limited data are available on either the extent of current compressed work week participation (possibly between 1.6% and 3.1% avoided commute trips) or the potential for expanded participation. Currently it is estimated that between 33% and 44% of private employers offer compressed work weeks. If this amount were doubled and employees participated at the same rate, 14.0 billion VMT would be reduced each year, leading to a GHG reduction of about 0.3% of on-road sources in 2030 (U.S. DOT 2010c).

Flexible work schedules do not reduce trips but may save fuel by shifting trips from congested to uncongested conditions. A reliable estimate of this benefit is not available.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Whether federal or state policies can have any significant impact beyond what the private sector will provide.	Extent to which long-term relocation effects offset short-term travel reductions from telework.

Other Benefits and Impacts. A variety of benefits have been associated with telework, AWS, and flexible work schedules, including enhanced worker productivity and morale, improved employee attraction and retention, and reduced overhead expenses. As long as these programs are voluntary, they can benefit employees with greater flexibility in work arrangements, the ability to schedule around personal and family activities, and reduced commuting time. Mandatory programs may benefit some workers but not others who prefer not to telecommute or work longer but fewer days.

Costs. Costs of alternative and flexible work schedules are negligible, aside from potential increased administrative and energy costs incurred in keeping facilities open longer. The cost of teleworking to employers and employees are typically higher. Requirements may include technical support, as well as additional computer equipment, communications equipment, and software purchases. According to a recent federal study that surveyed 18 agencies, the total annual cost of teleworking ranges from \$310 to \$5,420 per employee, with a median cost of \$1,088 per teleworker and an average cost of \$1,920 per teleworker (GSA 2006). Although these survey results led U.S. DOT (2010c) to judge the cost-effectiveness of telework strategies as low (at least \$1,200 per tonne CO_2e), it is likely that teleworking costs will continue to improve due to technological improvements and the widespread adoption of broadband technology.

Interactions. A significant increase in the cost of travel is likely to lead to more telecommuting and AWS because employees and employers have greater incentive to reduce their travel.

Development Status. Estimates of the proportion of U.S. employees who telework on a regular basis have varied, but this number has clearly risen substantially as the technology to support teleworking has advanced and fuel prices have increased. According to one recent national survey, the number of employees in the United States who teleworked at least once a month has more than doubled since 2001, rising from about 8 million in 2001 to 17 million in 2008, excluding self-employed and contract workers (WorldatWork 2009).

Implementation. Telework and AWS have primarily been implemented through private sector initiatives, although some public agencies have offered outreach programs, technical assistance, and incentives (such as tax credits or recognition) to encourage and assist private businesses. Examples include Oregon's business energy tax credit (which includes tax credits for telecommuting equipment), the Denver Regional Council of Governments' RideArrangers program, and the Maryland and Virginia Telework programs. The primary federal government role has been leadership/example-setting with its own employees. Tax credits or other incentives, such as recognition programs, could potentially be considered as well.

Barriers. Not all jobs are suitable for telework; many require face-to-face communication with clients or coworkers, making it difficult to perform from home or a telecenter. Similarly, jobs that require regular hours are not suitable for flexible schedules or compressed weeks. For a number of reasons, including concerns about the ability to supervise employees, some employers remain reluctant to offer teleworking or AWS options. The additional cost of working from home may be prohibitive for some individuals or employers, and not all employees may be interested in AWS or telecommuting. Surveys suggest that between half and three-quarters of all workers offered the option of telecommuting would be interested in doing so.

4.7. Ridesharing and Vanpooling

Description of Strategy. Ridematching, carpooling, and vanpooling—collectively termed "ridesharing"—are commuter-oriented strategies that seek to reduce VMT by increasing vehicle occupancies for work trips. New internet and mobile phone technologies s are facilitating the expansion of ridesharing to nonwork trips, allowing people to find suitable partners for trips that do not follow regular workday commute patterns. "Guaranteed ride home" programs, which reimburse employees for the cost of a taxi ride or rental car if they need to stay late or leave early due to an emergency, are an important strategy to support ridesharing.

Energy and GHG Impacts. The choice to rideshare depends on cost savings, ability to find suitable rideshare partners with similar origins and destinations, and personal factors, including work schedules and preferences for social interaction. Carpooling represents the second most common commuting mode in the United States, with a mode share of 12.2%, according to the 2000 Census. However, the majority of carpooling is informal – over 60% consist of two-person carpools with family members. Carpooling is also strongly associated with immigrant populations, with the carpooling rate among those who have been in the country less than 5 years almost double the rate for those who are native born (Pisarski, 2006). Vanpooling has a much lower mode share at 0.3% and is primarily found only in niche markets with relatively long-distance commutes to large employers. Financial incentives have been found to play significant roles in promoting ridesharing and vanpooling.

An evaluation of over 100 federally funded carpool demonstration projects in the 1970s found that program impacts translated into an estimated reduction of 0.3% of area-wide work trip VMT for carpool matching and 1.2% for broader programs (U.S. DOT 1978).[8] Considering that work trips are just under one-third of total VMT, this represents a reduction in area-wide passenger VMT of 0.1% to 0.4%. A more recent literature review found that area-wide ridesharing programs have led to a reduction in regional VMT ranging from 0.1% to 2.0%, with the authors of that review developing a "maximum reasonable estimate" of 0.4% (Apogee 1994). Considering that metropolitan VMT represents about four-fifths of total U.S. VMT, the cited range of 0.1% to 0.4% would translate into a nationwide reduction in on-road energy and GHG emissions of about 0.1% to 0.2% in 2030.

One study estimated the theoretical market potential of vanpooling, based on the number of employees working for larger employers and commuting longer distances, to be about 5% [COMSIS Corp. and Institute of Transportation Engineers (1993), in Evans and Pratt (2005)]. Estimates of GHG emission benefits of vanpools (and carpools) must account for not only the reduction in single-occupancy VMT, but also the increase in GHG emissions from van operations, and the additional circuity of the trip. Calculations for U.S. DOT (201(0c) suggested that vanpooling has the potential to reduce GHG by an additional 0.5 to 1.3 mmt CO_2e annually at current vehicle efficiencies, delivering a combined ridesharing and vanpooling emissions reduction of about 0.1% to 0.3%.

"Dynamic ridesharing" programs have been initiated by the private sector in the past few years. These programs use Internet and smartphone technology to match riders in or near real time. Because the technology is still new, there are no empirical estimates of the potential impact on overall travel in the United States. One study determined that about 20% of SOV commuters to a major university campus who live in eligible areas would consider using dynamic ridesharing at least occasionally (Deakin et al. 2011). The net impact is likely to depend on the price of fuel, and to vary locally depending on factors such as parking costs and the availability of HOV lanes.

The above discussion suggests that the impacts of ridesharing promotion have been modest when viewed in the context of overall travel. However, given that current private vehicle occupancies average 1.6 persons for all trips and less than 1.1 persons for work trips, the theoretical potential to increase vehicle

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[8] Although this may seem dated, it is the most comprehensive carpool program evaluation ever performed and most of the same considerations in carpooling apply today.

occupancy is quite large. In both the 1970 and 1980 Censuses, carpooling represented about 20% of work trips, compared with 13.4% in 1990 and 10.7% in 2008 (Chan and Shaheen 2011). If work trip carpooling rates were double the current levels, total VMT would be reduced by about 2%.[9] The International Energy Agency (2005) concluded that comprehensive deployment of carpool lanes, preferential parking, and carpool information could substantially increase carpooling and reduce vehicle travel in response to an oil shortage, saving 5% of total VMT and petroleum use in the United States and Canada at a very low cost per barrel saved. If average vehicle occupancies were increased from 1.6 to 1.8 persons per vehicle—the level reported in the 1983 Nationwide Personal Transportation Survey—up to 12% of VMT could be removed from the road.[10]

Key Uncertainties.

Policy Factors	Technology/Science Factors
Ability to implement widespread ridesharing/ vanpooling incentives in cities throughout the United States.	Additional gains that could be achieved in absence of significant travel price increases. Market penetration of dynamic ridesharing (users, trips per user).

Other Benefits and Impacts. Ridesharing and vanpooling can constrain schedules and lengthen commutes, which may be considered a reduction in mobility. As long as participation is voluntary, however, the perceived benefits more than offset the disadvantages.

Costs. Ridesharing program costs consist primarily of administrative expenses, along with marketing and outreach to promote the program. The administrative costs associated with rideshare matching programs are quite small compared to the costs that are required for a broadly effective marketing and outreach campaign. Vanpool expenses include vehicle purchase and operating costs, as well as administrative expenses. Costs are offset by vehicle operating cost savings to individuals, meaning that vanpool programs can cover most, if not all of their costs through subscription fees (Winters and Cleland undated). Some state and regional agencies have subsidized vanpools to increase viability and ridership (the Washington State DOT allocated $8.6 million to vanpool programs from 2005 to 2007). U.S. DOT (2010c) estimated a moderate cost-effectiveness of $80 per tonne CO_2e reduced for area-wide ridesharing programs.

Interactions. Higher prices for driving (via fuel prices or parking charges) will provide a greater incentive to rideshare. The popularity of ridesharing and vanpooling over time has been directly related to energy prices.

Development Status. Formal programs designed to increase carpooling and vanpooling were implemented in the 1970s and widely studied in the 1970s and 1980s. Many agencies continue to operate ridematching, vanpool formation, and outreach programs. Public sector support for these programs has varied, with more aggressive programs typically implemented in larger metropolitan areas with significant congestion problems.

Implementation. Regional vanpooling and ridematching programs are sometimes operated by MPOs, state DOTs, or transit agencies. Local programs may be operated by municipalities, transportation management organizations (nonprofit employer associations focused on a particular geographic area), or large employers. Vanpooling programs are frequently operated by private entities, such as VPSI, Inc.

[9] Assuming that all new carpoolers formerly drove alone, the work trip VMT represents about one-fifth of all VMT, and additional circuity from carpool trips (i.e., longer trip lengths to pick up passengers) is minimal.
[10] Again, assuming that all carpool occupants formerly drove alone and circuity is minimal; Charles River Associates (1988) reported that NPTS data show that the higher vehicle occupancy levels at the time were likely due in large part to economic factors (i.e., lower auto ownership and higher cost of driving relative to income than at the present) and to cultural and demographic factors (e.g., fewer single-person households), in addition to government promotion of ridesharing.

Increasingly, private entities are taking the lead in real-time ridematching (most suitable for nonwork trips) using mobile and web-based communications technology.

Barriers. Rideshare promotion programs are largely designed to overcome the barrier of needing to identify possible rideshare partners. Other barriers include the inconvenience of additional travel time to enable ridesharing, the possibility that ridesharing may create scheduling conflicts, and the challenge of accommodating side-trips for non-work activities. Many commuters limit ridesharing to days when they are only traveling from home to work and back. Because the length of the trip increases with the number of people in the rideshare arrangement, and because more partners with similar origins and destinations are needed, the market for vanpooling is limited to longer-distance commuters at large employers or in large employment centers.

4.8. Carsharing

Description of Strategy. Carsharing is a service that provides members with access to a fleet of vehicles on an hourly basis. Reservations are made on-line or by phone, and cars are parked at various locations within neighborhoods, at public transit stations, at employment centers, and on college/university campuses. The forms of carsharing are expanding with the advent of services that allow people to rent out their own cars to neighbors on an hourly basis.

Energy and GHG Impacts. Carsharing can decrease energy use and GHG emissions by allowing households to own fewer vehicles while still maintaining the option of mobility when needed, but at a higher marginal cost — which in turn will further reduce driving. On the other hand, it can increase GHG emissions for some households by providing existing zero or one-vehicle households with greater SOV mobility. Martin and Shaheen (2010) found that the average change in emissions across carshare participants is -0.58 tonnes GHG per household per year when considering direct emission reductions, and -0.84 tonnes GHG per household per year when considering avoided impacts (vehicles never purchased and driven). However, the impact varies widely with carsharing facilitating large reductions in the annual emissions of some households, while leading to small emission increases for other households. For reference, if carsharing were adopted by 3 million households in the United States, this would mean a benefit of 1.7 to 2.5 mmt CO_2e per year or a reduction in on-road emissions of 0.1% to 0.2%.[11]

Key Uncertainties.

Policy Factors	Technology/Science Factors
Extent to which federal policies can promote carsharing beyond what is being accomplished via the private sector and local partners.	Size of market for carsharing under existing and future land use and transportation cost conditions.

Other Benefits and Impacts. Carsharing provides cost savings to households that reduce their vehicle ownership and provides greater mobility to those who previously had no vehicles or fewer vehicles than drivers.

Costs. In most locations where it has succeeded, costs have been borne primarily by the private sector (recouped through membership and usage fees), although some municipalities and universities have subsidized start-ups, pilot projects, or small local programs.

Interactions. Carsharing is a complement to other alternatives to the private automobile. It is most viable in neighborhoods where transit, walking, and cycling are viable options. College and university campuses have been logical niche markets.

[11] This 3 million household estimate is two-thirds of Frost and Sullivan's projection of 4.4 million members in North America by 2016 (Zhao 2010).

Development Status. Carsharing is still in the early stages of deployment. Consulting firm Frost and Sullivan predicts 4.4 million members in North America by 2016, up from about 400,000 members at the beginning of 2010 (Zhao 2010).

Implementation. Carsharing services are typically provided by private sector companies. However, public sector support can be helpful to make carsharing viable, for example, by providing parking spaces, marketing support, and possibly financial assistance or revenue guarantees for start-up operations. Local governments, transit agencies, and universities all serve as public sector partners.

Barriers. Carsharing will not succeed in low-density, segregated use settings with limited transit service where a personal vehicle is required for mobility. Even in supportive environments, barriers may include the need to find parking; regulatory obstacles, such as zoning and business licensing laws; and start-up costs. In areas that are ripe for private investment in carsharing, public support is still needed to secure parking spaces and incorporate requirements or incentives for developers and property owners to accommodate carsharing in developments.

4.9. Educational and Marketing Campaigns

Description of Strategy. Public information campaigns directed at affecting travel behavior include general mass marketing, social marketing, and individualized marketing. Mass marketing campaigns (e.g., television, radio, billboards, print media) have been used to inform travelers in general about the availability of alternatives and incentives and direct them to more specific information on travel options. Social marketing makes use of social media, such as Facebook and Twitter, to target specific groups of people with common characteristics. Individualized marketing programs (typically implemented at a neighborhood level) utilize survey tools to identify individuals who are open to alternative modes of transportation, and provide individualized contact and customized information on modes favored by targeted respondents. The more rigorous individualized marketing programs may include one-to-one personal interaction, such as travel planning advice, while less costly programs simply rely on survey responses to target print and web media information.

Energy and GHG Impacts. Public information campaigns directed at travel behavior have had mixed success, with individualized and focused marketing showing somewhat greater promise than mass marketing as a travel reduction strategy. The benefits of mass marketing programs are difficult to quantify, but appear to be modest.

Three factors must be determined:

1) How many people recalled the message of the campaign?

2) How many changed their travel behavior as a result?

3) How permanent was the change?

An evaluation of the Commuter Connections program in the Washington, D.C. region concluded that a regional mass marketing campaign resulted in a 35% recall, a 0.1% mode shift for those who recalled the message, and a permanent change in modes for 19% of shifters. If the impact of outreach programs were extrapolated to the 50 largest metropolitan areas in the United States (representing just over half the country's population), the benefits would be a reduction of approximately 3.0 mmt CO_2e annually, with about one-tenth of these benefits attributed to mass marketing (U.S. DOT 2010c).

Individualized marketing shows potentially greater promise as a travel and GHG reduction strategy. Pilot individualized marketing programs that target both work and nonwork travel have reported VMT reductions in the United States of 2% to 8% for targeted populations (FTA 2006). The net effect across the entire population will depend on the proportion of the population that is: 1) willing to participate in individualized marketing programs; and 2) willing and able to make meaningful and permanent travel behavior shifts. No evidence is currently available on these parameters. However, if individualized marketing campaigns could effect a 5% VMT reduction in 5% to 10% of the U.S. population, the net effect would be a VMT reduction of 0.3% to 0.5% (U.S. DOT 2010c).

There have been anecdotal reports of effective social marketing efforts, such as Arlington, Virginia's "car free diet" campaign (Arlington County Commuter Services 2012). However, good quantitative estimates of the impact of social marketing, and its magnitude compared to other TDM marketing and outreach methods, are not available. Most likely, social media will complement individualized and mass marketing campaigns in locations where robust TDM programs and travel alternatives already exist.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Interest and institutional capacity to deploy individualized marketing programs on a widespread basis.	Effects of individualized marketing programs in a full cross-section of U.S. communities and extent of population that might respond to such programs. Effects of social marketing programs.

Other Benefits and Impacts. Public information campaigns provide benefits to travelers and consumers by helping them make more informed choices, which should increase welfare. Individualized marketing helps travelers better understand the travel options available to them, meaning that it may help improve mobility, as well as reducing the costs of travel for individuals.

Costs. The costs of public information campaigns can be modest in relation to investment in transportation infrastructure or services. Costs for broadcast advertising can be significant. However, costs for individualized marketing would be even greater if expanded to a broad population base. Annual regional TDM marketing budgets in Atlanta and Washington, D.C. have ranged from $2 to $3 million. Individualized marketing campaigns implemented in the United States have cost from $10 to $30 per participant, which would equate to $1 to $3 million for a city of 100,000 people.

Interactions. The extent to which individuals are willing to change travel behavior is affected by other factors, such as fuel prices and the quality of alternatives provided. The effectiveness of marketing measures therefore depends on land-use patterns, transit investments, and/or travel pricing that supports the use of alternative travel modes.

Development Status. Mass marketing campaigns have been implemented since the 1970s and have evolved to take advantage of new technologies, such as social media. Individualized marketing campaigns have been introduced and piloted within the past decade in a number of U.S. cities, as well as in Europe and Australia.

Implementation. Mass marketing has been undertaken by the federal government (e.g., the EPA's *It All Adds Up to Cleaner Air* campaign), state DOTs, regional agencies (MPOs and transit agencies), and state and regional air quality agencies. Individualized marketing has more often been implemented by municipal governments, given its geographically focused nature, although MPOs may play a role in supporting projects. For example, the Denver Regional Council of Governments has provided CMAQ funding for individualized marketing campaigns implemented by local jurisdictions.

Barriers. Public information campaigns do not face any significant feasibility constraints. For individualized and social marketing campaigns, institutional capability (as well as potential customer interest) to reach a large segment of the population has yet to be determined. Marketing strategies are not effective in locations where competitive travel options do not exist.

4.10. Real-Time Transit and Multimodal Information

Description of Strategy. Real-time transit and multimodal information strategies provide travelers with up-to-date information on transit options, stop locations, arrival times (both scheduled and predicted), and the time and cost of alternative travel choices for a specific trip. Real-time transit and multimodal information is disseminated through Internet sites, 511 telephone information systems, text messaging, smartphone applications, and changeable message signs at transit stops or stations. Real-time information is currently available for a limited number of U.S. transit systems, but this is expected to change in the near future. A 2011 report estimated that approximately 45 U.S. transit agencies provide some information on mobile devices, with approximately 15 of them providing real-time information on mobile devices (Schweiger 2011).

Energy and GHG Impacts. Energy and GHG reductions may result when travelers have more up-to-date and reliable information about transit options, helping to plan trips, reduce frustration associated with unexpected delays, and shift to alternative routes or modes.

There is very little quantitative information available on the potential mode-shift effects and resulting VMT, energy, and GHG reduction impacts of real-time transit information. One study estimated that widespread deployment of real-time public transportation information and targeted marketing is estimated to decrease car travel demand by 1.8% to 6.0% in urban contexts in the United Kingdom (Jones and Sloman 2003). Another study from Japan estimated a 20% reduction in emissions from a comprehensive program of travel information, primarily from mode-shifting. However, these results are unlikely to be directly applicable to the United States. The effects of multimodal information are likely to be greatest in areas where transit is already highly competitive with the automobile.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Role of public versus private sector in providing real-time transit and multimodal information.	Extent to which real-time information may facilitate mode shift to transit or other alternatives.

Other Benefits and Impacts. Travel information helps travelers adapt to uncertain conditions by changing routes, departure times, and modes, or being able to alert others to schedule changes. Travelers benefit both through reduced delays and reduced uncertainty.

Costs. Most transit agencies have equipped their buses with automatic vehicle location systems for fleet management purposes, so adding prediction services and messaging systems is the primary cost of informing riders of real-time schedules. Increasingly, agencies are turning to third parties to develop real-time applications and provide real-time information. Costs are not well documented, but appear generally modest. Several agencies have embraced an “open data” approach, allowing private companies and individuals to create applications to access data via the Internet, text messaging, and smartphones, providing real-time information at minimal cost to the agency (Schweiger 2011). Google Maps provides information on transit routing options in numerous U.S. cities.

Interactions. Transit and multimodal information is likely to be more effective at encouraging mode shifting in conjunction with supportive pricing policies, marketing to encourage use of travel alternatives, and convenient and reliable transit service.

Development Status. According to the U.S. DOT’s ITS Deployment Statistics database, as of 2010, about two-thirds of fixed-route buses nationwide were equipped with automatic vehicle location, but less than 5% of bus stops had electronic display of dynamic traveler information (U.S. DOT RITA). NextBus, probably the largest private provider of real-time transit information, serves more than 90 customer agencies, including public transit providers, universities, hospitals, and others (NextBus, Inc.).

Implementation. In the past, provision of real-time transit information to the public required equipping buses with automatic vehicle location and contracting with a private provider. It is likely that agencies will increasingly follow Boston's MBTA route and simply make automatic vehicle location data available to private developers. With the private sector increasingly taking the lead in providing traveler information across modes, the future role of the public sector beyond making data available and installing information signs at major stations and stops is not clear.

Barriers. As web-enabled mobile technology expands, the ability of travelers to access and utilize real-time information en-route is increasing significantly. Access to this information is challenging for those who do not have or are not comfortable using such devices. The potential of this strategy to encourage mode shifting is also limited by regional transportation options and the competitiveness of transit versus automobile.

4.11. Real-Time Traffic and Parking Information

Description of Strategy. Traffic information strategies provide motorists with up-to-date information on traffic conditions, incidents, and expected delays due to weather conditions, road construction, and special events. Traffic information is disseminated through a variety of mechanisms, including Internet sites, 511 telephone information systems, text messages and e-mails to mobile devices, in-vehicle GPS equipment, television public service announcements, radio announcements, and dynamic (changeable) signs. Emerging technologies also provide travelers with real-time information on the parking space availability.

Energy and GHG Impacts. Energy and GHG reductions result when better informed travelers and truckers can plan trips to avoid congestion by taking alternative routes, forego unnecessary trips, delay travel, or take alternative modes. Traffic information systems achieve GHG reductions both by improving efficiency (e.g., avoiding congestion) and reducing VMT. In some cases, however, better information can have mixed effects. For example, if travelers take a longer route to avoid an incident on their usual route, their VMT will increase. Real-time parking information can help reduce search times and associated VMT and possibly facilitate mode or destination shifting if parking at the desired location is determined to be full.

Some research has been conducted to quantify the VMT and GHG benefits of highway traffic information systems, but the impacts are diffuse and difficult to measure directly. The most quantitative information relies on simulation modeling. Available literature suggests that road status information programs may cause an increase in VMT (due to shifting to longer but faster routes) that roughly offsets the emissions benefits from reduced delay on the mainline (U.S. DOT 1999b). One simulation study predicted a statistically insignificant (0.1%) system-wide reduction in VMT from advanced traveler information system strategies and similarly insignificant (0.1% to 0.3%) reductions in emissions compared to a 1.5% reduction in overall vehicle hours of delay (Wunderlich, Bunch, and Larkin 1999). Another study using a computer simulation model concluded that information about traffic incidents and congestion could lead to a 2% reduction in vehicle emissions for Seattle, Washington, morning peak periods (Jensen et al. 2000). Cambridge Systematics (Urban Land Institute 2009) estimated the overall magnitude of GHG reductions that might be expected from further deployment of traffic information to be 0.6 to 1.8 mmt CO_2e in 2030 (less than 0.1% of on-road emissions) or only 0.1 to 0.5 mmt when considering induced demand effects. The limited evaluation data on freight route management systems has not quantified a VMT, fuel savings, or GHG benefit.

Studies around the world have found that between 8% and 74% of traffic in some congested business districts is due to searching for parking (Shoup 2005); although this has not been extrapolated to a nationwide basis. Parking search VMT is likely to be only a small fraction of total personal vehicle travel in the United States. It is not clear to what extent even up-to-the-minute, widely available information could reduce or eliminate parking searches.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Extent to which federal policies can promote real-time information beyond what is being accomplished via the private sector.	Effects of broader and more immediate information availability through proliferation of mobile devices. Effects and benefits of parking information systems if widely deployed.

Other Benefits and Impacts. Traveler information helps travelers adapt to congested conditions by changing routes, departure times, and modes, or alerting others to schedule changes. Travelers benefit both through reduced delay and reduced uncertainty. Computerized truck routing and dispatching systems have been widely adopted by the private sector and generally have been very cost-effective for carriers as a result of time and fuel savings.

Costs. Costs for developing statewide and metropolitan 511 traveler information systems have ranged from $133,000 to $1,028,000, with an average cost of $416,000 (U.S. DOT 2010c). Roadside equipment costs, such as dynamic message signs and highway advisor radios, constitute significant expenses. However, the use of GPS-enabled mobile devices for monitoring travel times has reduced the need for costly investment in monitoring infrastructure. Increasingly, private sector companies are providing traffic information to operating agencies for a fee and/or providing traffic information for customers at no cost to public agencies.

Interactions. If dynamic congestion pricing is implemented on a broader scale (with costs varying in real time), in-vehicle traveler information will be key to maximizing the effectiveness of this strategy.

Development Status. Various levels of highway traveler information are present in most major U.S. metropolitan areas. According to U.S. DOT (2010c), as of 2006, 63 of 100 surveyed metropolitan areas collected real-time freeway traffic data, covering 38% of lane miles. As of February 2008, 30 states had established 511 information systems. Private information providers, such as INRIX and Google, are developing increasingly comprehensive traffic conditions coverage, reporting on a much broader network of roads than was previously monitored through static systems.

Implementation. Traffic information services were first developed by state DOTs and MPOs. Recently, the private sector began taking a stronger role in providing traveler information. There is much private sector activity underway to provide customized delivery of traveler information to individual travelers via handheld and in-vehicle devices. Anonymous location tracking using GPS-enabled mobile devices is providing much more comprehensive real-time information than older monitoring technologies, such as loop detectors, cameras, and probe vehicles. The role of the public sector is not clear at this point, aside from providing advance information related to specific actions, such as work zone lane closures.

Parking information systems have been implemented at only a few major public facilities, such as airport parking garages and transit stations. On-street applications have been proposed using in-pavement or on-vehicle sensors to detect vacancies. The private sector also is experimenting with market-based applications allowing a driver leaving a parking space to auction it off to another driver.

Barriers. It was previously challenging to provide real-time information to travelers with radio, highway advisory sign, and non-mobile Internet communication technology. Widespread deployment and use of information infrastructure has been slowed by institutional challenges, requiring effective coordination among state, regional, and local agencies, as well as private entities. However, as web-enabled mobile device technology has expanded, the ability of travelers to access and utilize real-time information en route has increased significantly. The potential of this strategy is still limited by regional transportation options.

The technology and institutional responsibilities required for parking information systems represent barriers to deployment. Sensors are required to identify parking space occupancy, and coordination may be required between municipal transportation agencies and private parking garage operators.

4.12. Eco-Driving and Vehicle Maintenance

Description of Strategy. Eco-driving programs are designed to increase vehicle fuel efficiency through driver behavior and vehicle maintenance. Programs focused on driver behavior include general information about driving techniques, driver training programs, and in-vehicle instrumentation to provide real-time feedback on fuel economy. Techniques include avoiding rapid acceleration and unnecessary braking, obeying speed limits, performing proper gear shifting, and maintaining steady speeds on the highway. Applications using GPS-enabled personal mobile devices have the potential to provide in-vehicle feedback to drivers without specialized in-vehicle instrumentation. Public awareness campaigns and other outreach methods can be used to teach drivers how to properly maintain and equip vehicles to achieve the greatest fuel efficiency (e.g., tire inflation, lower rolling-resistance tires). Technologies such as tire pressure monitoring systems can also support proper maintenance. Truck fleet operators such as Staples and UPS have undertaken initiatives to save fuel that are focused on both driver training and vehicle technology (e.g., in-vehicle feedback, adjusting shift points). Other fleet operators have installed governors to limit highway speeds.

Energy and GHG Impacts. One study by the EPA found that aggressive highway driving can reduce gas mileage by 33%. Another study, by the California Air Resources Board, found an increase in fuel consumption of 5% to 14% with more aggressive urban driving cycles [International Energy Agency (IEA) 2005].

Eco-driving campaigns have been most extensively evaluated in Europe, with some limited assessments undertaken in the United States. European studies suggest potential for a short-term fuel savings of 15% to 25% per driver/vehicle, with longer-term benefits of 5% to 10% (U.S. DOT 2010c). Public education programs must be ongoing to deliver sustained benefits. Benefits from technology incorporated in the vehicle are long lasting. It is difficult to extrapolate U.S. benefits from these European results, given differences in vehicle technology—especially the greater prevalence of automatic transmissions in the United States. Other factors, such as the proportion of city versus highway driving, may also lead to differences.

Studies are also beginning to examine the potential benefits of technology-based eco-driving applications, such as the use of smartphones as in-vehicle feedback devices; eco-adaptive cruise control that adjusts speeds based on anticipated grades; and systems that utilize real-time traffic and signal timing information to provide eco-driving assistance based on anticipation of conditions ahead. Fuel savings estimates per driver typically range from 5% to 10%, with estimates of up to 20%, in congested urban conditions, although one study found only a 1% benefit on freeways. The potential market penetration of these methods (i.e., population willing and able to take advantage of them) is unknown. A very limited study in Southern California found that some drivers were already using eco-driving techniques, and most were willing to adopt eco-driving practices, especially if gas prices rose above $4 per gallon.

Anecdotal evidence also is available on the effectiveness of eco-driving for heavy-duty vehicle fleets. For example, by limiting the top speed of its delivery fleet trucks and implementing idling management technologies, Staples has improved fleet fuel economy by more than 25% since 2007 (Staples 2011). A Canadian study referenced by the EPA estimates that many fleets could achieve a 10% fuel economy improvement through driver training and monitoring. Similar improvements could potentially be realized in non-fleet heavy-duty vehicles, but will be easiest to achieve in fleets that are centrally managed.

Regarding the benefits of maintenance and equipment practices, the EPA and the DOE cite fuel savings of 4% for keeping an engine properly tuned, 3% for keeping tires properly inflated, and 1% to 2% for using the recommended grade of motor oil (DOE and EPA 2011). IEA (2005) estimates that properly inflating tires could reduce total U.S. fuel consumption from road transport use by 1.6 percent, accounting for program implementation effectiveness. Again, the extent to which consumers already practice these methods and the potential for more widespread adoption are unknown.

U.S. DOT (2010c) found a wide range of uncertainty in overall estimates of eco-driving's fuel-saving potential, ranging from 1.1% of on-road emissions (using conservative assumptions) to 5.7% (using the most optimistic estimates from European studies regarding per-vehicle benefits and market penetration). While the U.S. DOT report did not include information from the latest studies on eco-driving technology, these studies report per-vehicle impacts consistent with earlier estimates of eco-driving effectiveness, and provide alternative mobile technology-based implementation methods that may facilitate broader market penetration than could be achieved through government-run or mandated training programs. If a 10% per vehicle efficiency improvement could be achieved, the overall impact on fuel consumption could range from 1% at 10% market penetration to 5% at a very optimistic 50% market penetration. Both are in line with the U.S. DOT range of estimates. A combination of in-vehicle feedback technology and aggressive education campaigns would probably be required for the higher range of market penetration to be achieved.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Extent to which public sector eco-driving programs will emphasize voluntary provision of information, or will include mandatory training and/or vehicle modifications.	Market penetration of eco-driving assistive applications. Variation in adoption of eco-driving measures depending on fuel prices.

Other Benefits and Impacts. Eco-driving can deliver air quality and fuel savings benefits, both as a result of smoother driving patterns with less hard acceleration and improved vehicle maintenance. The overall effect on safety is equivocal, because monitor screens can be distracting, but eco-driving behaviors coincide with many safe driving practices.

Costs. Reliable information has not been produced on the costs of eco-driving programs and will depend on how the programs are implemented. The costs can be modest for general marketing and education materials, but will be much greater for programs that include dedicated driver training. Mobile device applications are available for free or at modest cost, although technology is evolving and quality may be an issue, at least in the short term.

Interactions. Both the general public and truck fleet operators are likely to become much more interested in eco-driving techniques as fuel prices increase. Eco-driving strategies and effects are likely to vary among different types of drivetrains (i.e., hybrid-electric, electric and conventional vehicles).

Development Status. Eco-driving programs are becoming common in Europe, with some of the most extensive programs found in the Netherlands, due the nation's air quality issues. In Sweden, eco-driver training became mandatory in education for new drivers starting in 2006. There are no mandatory eco-driving training programs for the general public in the United States, although a few states, MPOs, and federal agencies have developed general information campaigns or run small-scale pilot tests. The Massachusetts Registry of Motor Vehicles is incorporating eco-driving information in its driver tests. The EPA's SmartWay program has included information on eco-driving practices targeted at truck operators. Some private truck fleet operators have trained their drivers in eco-driving techniques and modified vehicles to reduce fuel use. Many new vehicles incorporate in-vehicle feedback mechanisms, such as instantaneous fuel economy gauges, although these vary in design and effectiveness.

Implementation. Voluntary/educational eco-driving campaigns could be conducted by agencies at any level (federal, state, or MPO/regional). The inclusion of eco-driving as part of mandatory driver training would be decided at the state level. Mandatory or voluntary efforts to include in-vehicle feedback in the design of new vehicles would need to be led by the federal government.

Barriers. The primary barriers to eco-driving programs in the United States are likely to be institutional; in particular, revising state driver training curricula to incorporate eco-driving practices and working with automobile manufacturers to incorporate in-vehicle feedback systems in new cars. Funding is also needed to carry out educational programs. Incentives may be needed to encourage private truck fleet operators to promote eco-driving practices by enrolling drivers in training programs and providing information and feedback. While in-vehicle feedback is an important contributor to eco-driving behavior, changes to vehicle design will take years to penetrate to the entire vehicle fleet. The use of personal GPS-enabled devices could allow feedback without in-vehicle systems, but consumers would need to be motivated and able to use such a device for this purpose.

4.13. Idle Reduction

Description of Strategy. Idle reduction strategies include education, laws, and technology to reduce long-duration idling of heavy vehicles. Heavy vehicle operators often leave their engines idling for extended periods to provide cab heat or air conditioning, storage cooling, and electrical power while they are stationary. Examples of idle reduction technologies include: providing electrical hookups at truck parking spaces; automatic shut-down/start-up systems for engines; heating and air-conditioning powered by on-board batteries or diesel generators (auxiliary power units); and statewide anti-idling laws to require or encourage adoption of anti-idling technology. Anti-idling laws can also be used to reduce idling of other heavy vehicles, such as buses at layovers, delivery trucks, or construction equipment.

Energy and GHG Impacts. According to data presented in U.S. DOT (2010c), sleeper cab trucks idle, on average, for about five hours a day while consuming about 1 gallon of fuel per hour. In comparison, an auxiliary power unit consumes about 0.3 gallon per hour and a battery consumes the equivalent of 0.05 gallon per hour. Cambridge Systematics (Urban Land Institute 2009) estimated nationwide GHG reductions of 6.1 mmt in 2030 from installation of heating and cooling systems in all sleeper cabs, and reductions between 0.4 and 1.3 mmt from truck stops having electrical hookups (truck stop electrification), depending on the extent of deployment (ranging from 1,500 to all 5,000 truck stops in the United States). The combined effects represent 0.1% to 0.4% of on-road vehicle emissions. The potential benefits of reducing short-term vehicle idling have not been quantified on a nationwide basis.

Key Uncertainties.

Policy Factors	Technology/Science Factors
Extent to which truck stops can be electrified. Whether or not uniform anti-idling legislation would be implemented nationwide.	Potential idle reductions from vehicles aside from sleeper cabs (market size, per-vehicle benefits, and ability to influence).

Other Benefits and Impacts. Investment in idle reduction technology results in cost savings over the long term due to reduced fuel costs. Truck owners' investment is generally paid back within two years at a diesel cost of $4 per gallon or within three years at $3 per gallon. Most idle reduction technologies reduce air pollution, at least for older trucks, with benefits concentrated in the vicinity of truck stops and other truck layover areas. For newer trucks, the magnitude of the emission benefits depends on the auxiliary power unit option—whether it has an after-treatment or is diesel-fueled, battery, or thermal—and the local electricity generation mix for truck stop electrification.

Costs. According to sources cited in U.S. DOT (2010c), the average one-time cost of implementing on-board idle reduction technologies is around $6,000 per truck. The infrastructure cost to electrify a parking space varies between $6,000 and $17,000, depending on the type of service offered. This cost is borne by the property owner and may be recouped through user fees. U.S. DOT (2010c) concluded that cost-effectiveness was moderate when considering only implementation costs ($20 to $50 per tonne CO_2e), but that significant cost savings may be realized if operational cost reductions are included.

Interactions. The GHG benefits of truck stop electrification depend on the local electricity generation mix. Future deployment of hybrid powertrains could make idle reduction technology unnecessary for short-haul vehicles.

Development Status. Idle reduction technologies and laws have been implemented to varying degrees throughout the country. According to sources cited in U.S. DOT (2010c), of the nation's 5,000 truck stops, 136 stops in 34 states were electrified as of October 2008; all or part of 25 states had implemented anti-idling laws as of 2009; and, as of 2006, 36% of trucks with sleeper cabs had on-board idle reduction technologies. A number of states have adopted anti-idling laws (e.g., five-minute limit) that apply to stopped vehicles in general.

Implementation. Idle reduction laws are typically the jurisdiction of states, and some state DOTs have taken the lead on electrifying truck stops. At the federal level, the EPA has provided incentives and assistance for idle reduction technologies to truck operators through its SmartWay program, including financing programs for the purchase or lease of approved idle reduction technologies.

Barriers. It will not be feasible to electrify the majority of truck parking spots, which are often dispersed (e.g., highway shoulders) (U.S. DOT 2010c). The most significant gains from reduced idling may result from on-board technologies, such as diesel-fired or battery-powered heaters and storage cooling air conditioning units. From a truck owner's perspective, the primary barriers to implementation of anti-idling technologies include initial startup cost, low fuel prices, and information dissemination. The added weight of auxiliary power units, which sometimes total a few hundred pounds, also may pose a barrier by incrementally reducing a truck's payload when considering a state or federal weight limits. A combination of regulatory reforms, price incentives, and outreach programs can help to combat these barriers. A national anti-idling law [such as the Model State Idling Law (EPA 2006)] would help to unify the existing patchwork of state laws and encourage more widespread adoption of idle-reduction technology. Even with anti-idling laws in place, their effectiveness depends on enforcement.

4.14. Speed Limit Reduction/Enforcement

Description of Strategy. This strategy would reduce speed limits on high-speed roadways to maximize fuel efficiency and/or increase enforcement of existing speed limits. Speed limit reduction or enforcement could be implemented on the Interstate Highway System, other limited-access highways, and major rural arterials.

Energy and GHG Impacts. Automotive fuel efficiency varies with vehicle speed, with peak efficiencies usually achieved between 30 and 60 miles per hour, depending on vehicle type, weight, aerodynamics, tire type, engine size, and other factors. The benefit of establishing a uniform speed limit will vary from vehicle to vehicle, and the fuel consumption benefit will also vary depending on the initial baseline speed of the vehicle. For example, a 5-mph speed reduction from 75 to 70 mph will provide a greater benefit than a 15 mph reduction from 60 to 55 mph.

A recent DOE evaluation estimated that a 55 mph speed limit implemented at the national level could result in a fuel consumption savings between 175,000 and 275,000 barrels of oil per day or about 27 to 43 mmt CO_2e per year. This represents about 1.6% to 2.4% of on-road vehicle fuel consumption and emissions. For this assessment, the DOE assumed that 35% of all on-road mileage would be impacted by the reduced speed limit, along with a 50% compliance rate [2008 General Accountability Office study, as reported in U.S. DOT (2010c)].

Key Uncertainties.

Policy Factors	Technology/Science Factors
Willingness to reestablish federal speed limit (and at what level).	Impacts of future vehicle technology on relative efficiency at different speeds.
Consistency in enforcing speed limits.	Rate of compliance with different levels of speed limits.

Other Benefits and Impacts. Speed limit reductions would result in fuel savings and other vehicle operating cost savings, but also increased travel times. Speed limit reductions would also have safety benefits and could result in reductions of some criteria pollutants and precursors, especially oxides of nitrogen.

Costs. The costs associated with implementing speed limit reductions are relatively small, including new signage and public outreach and education efforts. Ongoing enforcement costs will be more significant, although these can be recouped through fines. IEA (2005) estimated national enforcement costs of approximately $600 million annually for personnel or $800 million initially for speed camera deployment. U.S. DOT (2010c) provided an illustrative example in which $1.5 billion in additional travel time costs would be realized, compared with $3 billion in fuel savings. A 1984 National Academy of Sciences analysis estimated that 4,000 traffic fatalities were averted per year as a result of the 55-mph national speed limit, which translates into a savings of $24.4 billion when using the EPA Science Advisory Board $6.1 million "value for a statistical life" (U.S. DOT 2010c).

Interactions. Changes in vehicle technology could affect the magnitude of benefits from speed limit reductions. For example, fuel consumption in light-duty hybrid electric vehicles rises more quickly above 50 mph when compared with conventional vehicles (U.S. DOT 2010c). The higher baseline fuel economy reduces the total fuel consumption impact in absolute terms. A European study found that GHG emissions from modern vehicles tend to show much less dependence on vehicle speeds (at least at highway speeds) compared with older vehicles (Carsten et al. 2008).

Development Status. The Emergency Highway Energy Conservation Act of 1974 first instituted a nationwide speed limit of 55 mph with the goal of reducing total on-road fuel consumption by 2%. However, the law was met with widespread resistance and poor overall compliance, and was ultimately repealed in 1995.

Implementation. Speed limits are currently set by states, although the federal government could re-impose a national speed limit (or different speed limits for different types of roads). States are also responsible for enforcement and would need to support any national policy (or have a strong incentive for enforcement) for it to be effective. Reduced speed limits can be implemented very quickly, limited only by the time required for re-signage and public notification.

Barriers. Barriers to speed limit reductions are social and political, rather than technical. The previous national speed limit initiative met with substantial resistance across the country and was limited in its effectiveness by inconsistent enforcement (U.S. DOT 2010c).

5. Summary of Strategy Impacts

The primary source used to estimate the potential impacts of strategies discussed in this report is U.S. DOT (2010c), which provides the most consistent, comprehensive and up-to-date review of the literature on travel reduction and efficient driving measures. In this section, the estimates from this report are supplemented with information on other emerging strategies identified in the literature review. Individual and combined results from other recent sources that examine multiple strategies are also presented for comparison.

5.1. Estimates for This Study

Table 5.1 summarizes the percentage reductions estimated by Cambridge Systematics for individual strategies in this report. The data are shown as a percentage of on-road vehicle emissions, rather than in relation to all transportation emissions, as is presented in the primary source document (U.S. DOT 2010c). While these estimates were projected for 2030, most of them should be valid for the following 10 years, assuming rapid implementation of strategies. Exceptions include transit and nonmotorized improvements, which are infrastructure-intensive and will take longer to fully implement. Most of the percentage reduction estimates are also independent of varying baseline transportation emissions, considering new fuel efficiency and low-carbon fuel standards.

Table 5.1. Individual Strategy Impacts in 2030

Strategy	Percentage of On-Road Energy/GHG Reduction
Pricing	
PAYD Insurance (Mandatory)	2.5%
VMT Fee – $0.02-$0.05/Mile	1.0%–2.5%
Congestion Pricing	0.5%–1.1%
Transit Improvements	0.4%–1.1% (2030) 0.6%–2.0% (2050)
Nonmotorized Improvements	0.3%–0.8%
Parking Management	0.3%
Work Site Trip Reduction/Employee Commute Options	0.2%–1.1%
Telework and Alternative Work Schedules	0.9%–1.1%
Ridesharing and Vanpooling	0.1%–2.0%
Carsharing	0.1%–0.2%
Educational and Marketing Campaigns[a]	0.3%–0.5%+
Real-Time Transit and Multimodal Information	Unknown
Real-Time Traffic and Parking Information [a]	0.1%+
Eco-Driving and Maintenance	1.1%–5.0%
Idle Reduction	0.1%–0.4%
Speed Limit Reduction/Enforcement	1.7%–2.7%
Combined Effects (see text for explanation)	**7.0%–15.3%**

[Source: Estimates from the literature as described in Section 4.0, primarily based on U.S. DOT (2010c).]
Moderate to substantial uncertainty is associated with most estimates.
Provision of a point estimate rather than a range does not imply greater certainty.
[a] + Denotes additional, unknown effect of emerging information technologies.

Most, but not all, of these strategies can be implemented independently of each other and do not reflect overlapping or compounded effects. Exceptions include telework/AWS and ridesharing/vanpooling, which are often components of worksite trip reduction programs. Information on travel options should lead to additional increases in transit, nonmotorized travel, and ridesharing. Most individual strategies show an impact of 1% or less in a 2030 time frame. Pricing strategies may produce larger effects, depending on the level of the price increase.

Combined scenarios were also evaluated using data from U.S. DOT (2010c) and supplemented by additional data as presented in this report. The impacts of individual strategies were combined multiplicatively to avoid double counting. A scenario consisting of all of the strategies included in Table 5.1, except for the VMT fee and ridesharing/vanpooling (assumed to be covered in worksite trip reduction), resulted in a combined reduction of on-road emissions by 7.0% to 15.3% in 2030.[12] Additional pricing measures (i.e., a VMT fee or carbon tax) would increase the estimate in proportion to the size of the price increase. Adding land use provides a combined effect of 8.5% to 19.8%. (Information on land-use strategies is covered in a separate TEF report.)

5.2. Estimates from Other Sources

Other recent studies have examined the potential for reducing travel, energy consumption, and GHG emissions through travel behavior and efficiency strategies.

Cambridge Systematics (Urban Land Institute 2009) examined six strategy "bundles." The study accounted for synergies among strategies. In particular, transit, bicycle, pedestrian, and carsharing strategies were assumed to be more effective in areas of greater population density, and therefore more effective under more aggressive land-use scenarios. The impacts from individual strategies were combined multiplicatively to avoid double counting. At aggressive levels of implementation, the six bundles demonstrated a reduction in GHG emissions ranging from 3% to 11% in 2030 and as much as 18% in 2050.

Greene, Baker, and Plotkin (2011) estimated light-duty VMT changes from six strategies, as shown in Table 5.2. Estimates in 2030 range from 1.4% to 8.2%, with a "medium" scenario estimate of 3.0%. This study encompasses fewer strategies than the U.S. DOT and Cambridge Systematics studies, so impacts are smaller. On the other hand, percentages shown are compared to a light-duty baseline, rather than all on-road or surface transportation.

Table 5.2. Light-Duty VMT Reduction Estimates in 2035

Policy/Mitigation Option	Low	Medium	High
Road User Tax on Energy	-0.19%	-0.49%	-0.64%
Carbon Price	-1.20%	-1.20%	-1.20%
Pay at the Pump Insurance	0.00%	-0.97%	-0.97%
Trip Planning and Route Efficiency	0.00%	-2.00%	-4.00%
Ridesharing	0.00%	-0.70%	-1.40%
Land Use and Infrastructure Development	0.50%	-1.00%	-2.00%
Total Excluding Land Use	**-1.4%**	**-3.0%**	**-8.2%**

[Source: Greene, Baker, and Plotkin (2011)]

Note: The original study authors did not provide a summation of individual strategies. This is done here to provide a comparison of the magnitude of impacts with our estimates. Land use is excluded from the total because it is discussed in a separate report.

The ICF International study (EPA 2011b) evaluated the potential combined effects of TDM, land-use policies, transit service improvements and fare reduction, and parking and road pricing in a study using data from 15 cities in conjunction with a sketch-planning travel demand evaluation model. The study extrapolated impacts to nationwide urban light-duty vehicle VMT and emissions. As shown in Table 5.3, the study estimated impacts in 2030 ranging from 0.1% for TDM to only 3.4% for all strategies

[12] Effects are reported for strategies combined multiplicatively. For example, assuming they have independent effects, 10 strategies that each reduce VMT by 1.0% should produce an overall VMT reduction of 9.6% (0.99^{10}) rather than 10.0% if the effects were simply added.

combined. Impacts in 2050 were estimated to range from 0.3% for TDM to only 8.8% for all strategies combined (Grant et al. 2008). Impacts ranged as high as 12% to 16% in some metropolitan area clusters. The set of strategies evaluated is somewhat more limited than those included in the U.S. DOT and Cambridge Systematics studies, which helps account for the smaller predicted impact. The 2030 combined estimate is similar to the "medium" estimate from Greene, Baker, and Plotkin (2011), although the list of strategies is somewhat different.

Table 5.3. Light-Duty Vehicle CO_2 Reduction Estimates in 2030 and 2050

Policy/Mitigation Option	2030	2050
Region wide TDM	0.10%	0.26%
TDM + land-use changes	1.01%	2.97%
TDM + land-use changes + transit fare reduction	1.40%	4.19%
TDM + land-use changes + transit fare reduction + transit service improvements	1.44%	4.30%
TDM + land-use changes + transit fare reduction + transit service improvements + parking fees	2.92%	6.98%
TDM + land-use changes + transit fare reduction + transit service improvements + mileage fees	1.94%	6.28%
TDM + land-use changes + transit fare reduction + transit service improvements + parking fees + mileage fees	3.42%	8.83%

[Source: ICF International (EPA 2011b)]

IEA (2005) found potential impacts of transit, carpooling, telework/work schedules, and eco-driving that, when summed, total about 20% (Table 5.4). The most effective individual strategies are carpool infrastructure (including HOV lanes) and programs, telecommuting, compressed work weeks, and eco-driving. However, the study assumed extremely aggressive deployment, such as might be motivated in a major oil supply disruption, which might be unrealistic in the absence of a strong imperative. The results are not tied to a particular evaluation year.

Table 5.4. Estimated Road Transport Fuel Savings for U.S./Canada Region

Policy/Mitigation Option	2030
Public Transit – Fare reductions (50%-100%)	0.4%–0.7%
Public Transit – Service increases	0.3%
Bus and HOV enhancement/expansion	0.03%–0.06%
Carpooling infrastructure and programs	6.8%
Carpooling program	1.0%
Telecommuting	4.4%
Compressed four-day work week	3.1%
Eco-driving campaign	5.0%
Total[a]	**18.6%**

[Source: IEA (2005)]

[a] The original study authors did not provide a total across all strategies. This is done here to provide a comparison of the magnitude of impacts with our estimates. The total excludes "carpooling program" and includes the lower fare reduction estimate (50%). The total is estimated by combining strategies multiplicatively (see discussion of Table 5.1).

Top-down, aspirational or "scenario" estimates of potential travel activity and system efficiency benefits have also been developed. These estimates make assumptions on what percent VMT reduction is needed or can be obtained to contribute to certain non-VMT GHG-reduction strategies, rather than building from the bottom up based on the effects of individual strategies. As an example, an EPA "wedge analysis" of the transportation sector[13] assumes that a 10% to 15% reduction in VMT from TDM strategies can contribute to GHG reductions, along with vehicle efficiency and low-carbon fuel improvements (Mui et al. 2007).

5.3. Key Interactions

The benefits of the strategies shown in Tables 5.1 to 5.4 are not necessarily additive (or multiplicative), as the strategies are not entirely independent. For example, pricing works in part by encouraging people to make use of other strategies, such as transit, ridesharing, telecommuting, and more efficient driving. On the other hand, pricing may be more effective when applied in conjunction with other supportive strategies, especially those that provide travel alternatives such as transit, land use, and nonmotorized travel, as well as information about alternatives (i.e., the price elasticity of travel might vary depending on the context in which it is applied). These alternatives are also likely to be most effective when applied in combination.

Quantitative evidence on interactive effects is limited. A study using data from a pilot mileage fee experiment in Portland, Oregon, found that congestion pricing is more effective when implemented in traditional (dense and mixed-use) settings, as compared to suburban (low-density, single-use) settings (Guo et al. 2011). A study by the Center for Transit-Oriented Development compared CO_2 emissions per household and characterized location efficiency based on characteristics including access to rail transit and neighborhood land use. The study found that, when compared to the average metropolitan area household, households in transit zones that fell into the two middle categories of location efficiency produced 10% and 31% lower emissions, and households that fell into the highest location-efficient category produced 78% lower emissions (Center for Transit-Oriented Development and Center for Neighborhood Technology 2009).

In contrast, for this report, Cambridge Systematics reviewed six studies that modeled transit, land use, and pricing scenarios using regional travel demand models and found no consistent benefits of combined effects. The synergistic effect of combined strategies (compared to the sum of the same individual strategies) ranged from roughly -20% to +20%, depending on the study and scenario. Most studies that have developed estimates of price elasticities have not reported separate elasticities that depend on urban context or the provision of other travel reduction strategies. Cambridge Systematics also compared data from TDM programs implemented in the United States and Europe. The comparison found that, while baseline use of alternative modes was much higher in Europe, the incremental effects of the TDM information and incentives were similar whether implemented in European cities with high transit service and population densities or in U.S. cities with lower levels of transit service and population densities (Cambridge Systematics, unpublished data).

[13] So called because each policy creates a growing benefit over time that is shaped like a wedge when plotted. The wedges are stacked to show the total reduction as compared to a baseline.

6. Federal Actions

This section documents possible federal actions that might influence travel reduction and efficient driving. It begins with a discussion of the various roles and responsibilities that federal, state, and local authorities may have for travel reduction and efficient driving measures. It continues with a review of the history of federal involvement in these measures and an overview of existing projects and programs. It concludes with a discussion of other potential actions the federal government could take in relation to the strategies discussed in this report. This section is not intended to promote or propose such actions, but to provide information about the framework, history, and estimated effectiveness of federal action.

6.1. Federal versus State and Local Roles

Federal, state, regional, and local agencies play various roles in implementing travel reduction and efficient driving measures. State DOTs, MPOs, and transit agencies have the primary authority and/or responsibility for most of these types of programs. However, federal policies and priorities are also reflected by transportation law, regulations, and funding programs. The various roles, as assessed by Cambridge Systematics for this report, are briefly described here. As an overview of roles, this summary does not explore detail that may vary among states and localities.

Pricing –

- PAYD Insurance – Primarily an issue of state jurisdiction via insurance industry regulation.
- VMT or Carbon Fee – May be assessed at the federal or state level as an alternative or supplement to fuel tax revenue. Carbon fees are most likely to be assessed at the federal level.
- Congestion Pricing – Most likely to be implemented by a state DOT via its jurisdiction over state highways or by an MPO working in partnership with the state. Cordon pricing has been studied by major municipalities.

Transit Improvements – Directly implemented by local or regional transit authorities, MPOs and state DOTs are involved in planning and funding. The federal government is a significant source of funding.

Nonmotorized Improvements – Generally implemented by state DOTs and local governments as part of design policies and capital improvement priorities (roads and trails) and by local governments as part of site design/development review, MPOs may also set policy and establish priorities for inclusion of nonmotorized facilities in regional transportation plans. Federal roles have included designated funding, as well as design requirements or guidelines for federal-aid highway projects.

Parking Management – Usually under the authority of local governments, federal and state tax laws may apply, including provisions for pretax employee parking benefits.

Worksite Trip Reduction/Employee Commute Options – The federal government, state agencies, MPOs, regional transit agencies, and local governments have all played lead or supporting roles in implementing worksite trip reduction programs. Some programs have specific levels of responsibility (e.g., federal or state tax incentives, municipal requirements to implement TDM in new development).

Telework and AWS – Federal, state, and regional agencies have all created programs to encourage and support employers in promoting these programs. Federal and state tax laws may apply.

Ridesharing and Vanpooling – State DOTs and MPOs are most commonly the lead public agencies in promoting and facilitating these options. Transit agencies sometimes run vanpool programs.

Carsharing – Local governments typically take the lead on working with private vendors to implement these programs.

Education and Marketing Campaigns – Initiatives to change travel behavior through the provision of information may be undertaken by any level of government.

Real-Time Multimodal Information – State DOTs and MPOs may both coordinate ITS deployment efforts across modes. Transit agencies also play an essential role in making transit information available.

Real-Time Traffic and Parking Information – State DOTs and MPOs may both coordinate ITS deployment efforts across modes. Local governments typically lead efforts to provide parking information.

Eco-Driving – Federal agencies, state DOTs, and MPOs have all led eco-driving campaigns. State motor vehicle agencies take the lead on driver training curricula. Vehicle regulation, such as for real-time feedback mechanisms, falls to the federal government.

Idle Reduction – States and municipalities may adopt and enforce limitations on in this area. Educational campaigns may be conducted by any level of government.

Speed Limit Reduction/Enforcement – States are currently responsible for setting and enforcing speed limits on state roads.[14] However, there is past precedent for establishment of national speed limit.

Responsibilities for implementation of travel reduction and efficient driving measures lie at various levels. State DOTs and MPOs, as federally designated transportation planning organizations, have authority for transportation system planning and policies. Authority for design, construction, and operation of the system lies primarily in the hands of state DOTs (for state roads), municipalities (for local roads), and transit authorities. State and local governments have authority over tax policies, and states may implement other regulations. Municipalities are responsible for land development. Voluntary programs, such as educational and marketing, may be undertaken at any level.

Federal roles that may influence these strategies include statewide and metropolitan planning requirements; transportation funding programs and performance criteria; research and development activities; and environmental regulations (such as air quality standards) that have implications for transportation planning.

6.2. History of Federal Involvement in Travel Reduction and Efficient Driving

This summary is based on Cambridge Systematics' research and experience. The history of federal involvement in travel reduction and efficient driving dates as far back as World War II efforts to conserve fuel. The Clean Air Act Amendments (CAAA) of 1970 first required transportation control plans for areas unable to meet air quality standards despite new automobile emission regulations. These requirements were strengthened in the CAAA of 1977. U.S. DOT regulations in 1981 required that priority for transportation funds in nonattainment areas be given to transportation (air quality) control measures (TCM) in state air quality implementation plans (Weiner 1997). The fuel shortages of 1973–1974 added the goal of energy conservation to emission reductions. Passage of the National Environmental Policy Act in 1969 contributed to the TDM emphasis. In preparing environmental impact statements, transportation agencies had to begin to look at alternatives to building the fully desired road capacity, including what steps could be taken to either reduce or eliminate adverse impacts.

Both the federal transportation and energy agencies played a significant role in funding research and demonstration projects on travel reduction methods during the subsequent decade. The U.S. DOT's Urban Mass Transit Administration, which in 1991 became the Federal Transit Administration, funded numerous research and demonstration projects on ridesharing, vanpooling, transit service and fare innovations, auto-restricted zones, and other TDM measures. The U.S. DOT also began a road pricing demonstration program in 1976 (Weiner 1997). The Federal Energy Administration (FEA), which became

[14] Cities set speed limits on municipal roads but they are less relevant for energy because the high-speed facilities where speed limits lead to fuel savings are almost always state roads.

the DOE in 1977, also funded research on fuel savings from TDM strategies and supported the development of TDM analysis methods to support the development of State Energy Conservation Plans as provided for by the Energy Policy and Conservation Act (PL 94-163) (*c.f.* Cambridge Systematics 1976). The EPA also contributed funding to these efforts, for example, through an evaluation of compressed work week for federal employees in the Denver region (Atherton et al. 1982).

A look at the history of carpooling is illustrative of federal involvement in TDM. The 1974 Emergency Highway Energy Conservation Act allowed federal highway funds for106 carpool demonstration programs in 96 U.S. metropolitan areas through 1977. In 1975, FHWA began publishing guidebooks on carpooling and vanpooling. The U.S. DOT established the National Ride-Sharing Demonstration Program in 1979 with the objective of increasing ridesharing use by 5%. As part of the National Ride-Sharing Demonstration Program, the U.S. DOT and the DOE developed computerized ridematching (Chan and Shaheen 2011).

Federal activity on TDM waned in the 1980s, as oil supplies stabilized, prices fell, and political leadership changed. It resumed in the 1990s, due to the adoption of the Clean Air Act Amendments of 1990, which greatly increased the focus on transportation emission reductions. The 1990s also saw a growing recognition of the importance of intermodalism and the costs of urban congestion: the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 included a multimodal focus for the first time. The strong linkage between ISTEA and the 1990 CAAA, which required transportation programs to "conform" to plans to attain ambient air quality standards, provided motivation to fund air quality improvement programs through VMT, congestion reduction, and clean technology. Among the programs funded by ISTEA were some that could be used to fund TDM, most notably CMAQ. In addition, the Energy Policy Act of 1992 allowed employers, for the first time, to offer tax-free vanpool benefits and substantially increased the allowable limit for transit benefits (Weiner, 1997). As of 2011, employers could provide workers with up to $230 per month in tax-free transit and vanpool benefits (National Center for Transportation Research 2011); however, carpool subsidies remain taxable (Winters 2010).

The U.S. DOT and the EPA also undertook a number of technical assistance efforts during this time. For example, in the early 1990s, the U.S. DOT sponsored a major study to evaluate TDM programs and develop an evaluation tool known as the TDM Model (COMSIS Corp. and Institute of Transportation Engineers 1993). The early 1990s also saw the advent of programs to promote and evaluate telecommuting. Pursuant to its authority in the CAAA, the EPA published a set of "transportation control measure information documents" (Cambridge Systematics 1992). The agency subsequently funded additional research into TCM effectiveness, as well as the development of TCM assessment methods and models, such as the COMMUTER Model (first published in 2001). The EPA's involvement has continued with programs to reduce travel and emissions, including the Commuter Choice Leadership Initiative/Best Workplaces for Commuters program (2001–2007) and the SmartWay program focused on heavy-duty fleets (ongoing).

Rising oil prices in the 2000s have renewed interest in energy conservation, and steps have been taken to consider GHG emissions in transportation planning. In 2005, President George W. Bush signed into law the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), which included the latest round of guaranteed funding for surface transportation. A study by the World Resources Institute found that six of 48 reviewed SAFETEA-LU programs documented a reduction in VMT, GHG emissions, and oil consumption (World Resources Institute and EMBARQ 2011).[15] Since 2005, the U.S. DOT has supported state and MPO development of GHG reduction strategies through guidance and peer exchanges on planning practice, as well as development of technical

[15] The six programs are Safe Routes to School, Nonmotorized Transportation Pilot Program, Value Pricing Pilot Program, Congestion Mitigation and Air Quality Program, Job Access and Reverse Commute Program, and the Paul S. Sarbanes Transit in Parks Program.

analysis methods. The EPA and FHWA continue to provide guidance on analytical methods to estimate the effects of travel efficiency strategies on GHGs and criteria pollutants (EPA 2011a; FHWA 2012).

The two-year transportation reauthorizing legislation passed in 2012, Moving Ahead for Progress in the 21st Century (MAP-21), includes a greater focus on performance measurement, although it does not include performance measurement for GHG emissions and/or energy. Requirements or incentives for integrated transportation and land-use planning have also been discussed as part of longer-term reauthorizing and energy legislation, with some proposals modeled after California's Senate Bill 375 that required regional sustainable community planning to meet GHG reduction targets. However, MAP-21 does not include major new initiatives to reduce transportation energy use or GHG emissions.

6.3. Recent and Current Projects and Programs

This section provides an overview of federal programs related to travel reduction and efficient driving, as of 2012. Cambridge Systematics selected these programs as major illustrations of the current federal role, and some federal linkages to travel reduction and efficient driving may not be listed here.

6.3.1. Federal-Aid Highway Programs

6.3.1.1. Congestion Mitigation and Air Quality Improvement Program

The CMAQ program was conceived under ISTEA to support surface transportation projects that contribute to air quality improvements and provide congestion relief. Among other things, CMAQ funds have been used for programs that reduce vehicle trips, including carpool/vanpool projects, operations of new public transit services, and travel demand management programs. Evaluations of the CMAQ program, undertaken in 2002 and 2008, provide some of the most comprehensive assessments of TDM measures to be found in the recent literature (TRB 2002; ICF International 2008).

More information: http://www.fhwa.dot.gov/environment/air_quality/cmaq/.

6.3.1.2. Transportation Enhancements Program

Transportation Enhancements activities are federally funded, community-based projects that expand travel choices and enhance the transportation experience by improving the cultural, historic, aesthetic, and environmental aspects of transportation infrastructure. The program includes 12 distinct categories of projects. Some of these are projects that reduce vehicle travel, such as creation of bicycle and pedestrian facilities, streetscape improvements, refurbishment of historic transportation facilities, such as intermodal transportation centers.

More information: http://www.fhwa.dot.gov/environment/te/index.htm
and http://www.enhancements.org.

6.3.1.3. Safe Routes to School Program

Safe Routes to School is a program designed to improve bicycle and pedestrian connections to school and to facilitate the planning, development, and implementation of projects that will improve safety, reduce traffic, reduce fuel consumption, and decrease air pollution near schools. Based on analysis by the Safe Routes to School Task Force, for a typical one-school program, an increase in 100 students walking or biking to school could reduce 33,000 pounds of CO_2 emitted and save nearly 1,700 gallons of gasoline per year.

As included in SAFETEA-LU, FHWA was responsible for administering the $612 million in federal funds that were authorized for the state Safe Routes to School programs between fiscal year 2005 and 2009. Congress has continued to extend the program in the absence of long-term transportation reauthorization.

More information: http://www.saferoutesinfo.org/,
and http://www.fhwa.dot.gov/safetealu/factsheets/saferoutes.htm.

6.3.1.4. Nonmotorized Transportation Pilot Program

The Nonmotorized Transportation Pilot Program was funded through SAFETEA-LU to demonstrate, in four different communities, the potential to increase active transportation by improving nonmotorized transportation infrastructure. The goal was to shift substantial numbers of trips from driving to walking and biking. Based on an interim report, the four pilot communities demonstrated 1% to 4% reductions in daily VMT, an estimated reduction of 0.5 mile daily per adult. The communities' reductions in VMT from infrastructure improvements through the pilot program totaled 156 million miles annually. The program suggests that an expansion of these improvements in other communities could shift trips from driving to nonmotorized modes.

More information: http://www.fhwa.dot.gov/environment/bikeped/ntpp.htm.

6.3.1.5. Value Pricing Pilot Program

The Value Pricing Pilot Program was renewed through SAFETEA-LU to provide funding to support studies and implementation aspects of a tolling or pricing project. The purpose of the Value Pricing Pilot Program is to demonstrate whether and to what extent roadway congestion may be reduced through application of congestion pricing strategies, and the magnitude of their impact on driver behavior, traffic volumes, transit ridership, air quality, and availability of transportation funds.

Based on a 2009 program evaluation, experimental projects have shown that driver behavior changes significantly when drivers are made fully aware of the real costs of driving and given an opportunity to avoid some of these costs by changing their travel behavior. One pilot project from the Port Authority of New York and New Jersey concluded that variable tolling resulted in 7.4% of auto users modifying their trips, including 20% of the "modifying" group shifting to transit. A project in Portland, Oregon, found that 14% of households that were charged rush hour fees had a household member switch to transit to save money. A region-wide pricing project in Seattle, Washington, found that 80% of households reduced driving or shifted away from car travel.

More information: http://ops.fhwa.dot.gov/tolling_pricing/value_pricing/index.htm.

6.3.2. Federal Transit Programs

6.3.2.1. Job Access and Reverse Commute Program

The Job Access and Reverse Commute program was created to help provide low-income workers with access to jobs where conventional transit options are reduced or not available. According to a 2008 study reviewing 23 Job Access and Reverse Commute programs, 14.2% of Job Access and Reverse Commute riders had switched to transit from personal automobiles. A larger percentage of rural workers (20.2%) shifted from auto to transit when compared to workers in large metropolitan areas (10.5%).

More information: http://www.fta.dot.gov/funding/grants/grants_financing_3550.html.

6.3.2.2. Paul S. Sarbanes Transit in Parks Program

The Transit in Parks program was founded to decrease vehicle congestion in national park areas, protecting natural, cultural, and historic resources. This program supports capital and planning expenses for new or existing alternative transportation systems, as well as nonmotorized transportation systems in America's national parks, wildlife refuges, and national forests.

A review of 10 case studies in 2009 showed reductions in vehicle trips and corresponding GHG emissions in parks, including in Acadia National Park, Glacier National Park, Devils Postpile National Monument, and elsewhere.

More information: http://www.fta.dot.gov/funding/grants/grants_financing_6106.html.

6.3.3. DOE and EPA Programs

6.3.3.1. Eco-Driving Information Tips

The DOE and the EPA include information on eco-driving on their jointly sponsored fueleconomy.gov website. Tips include driving "sensibly," observing the speed limit, removing excess weight, and avoiding excessive idling. The use of cruise control and overdrive gears are also recommended. The website provides estimates of gasoline and cost savings from these measures.

More information: http://fueleconomy.gov/feg/driveHabits.shtml.

6.3.3.2. SmartWay Transport Partnership

SmartWay is a public-private collaboration between the EPA and the freight industry. Projects within the partnership help carriers find ways to improve efficiency and reduce fuel costs, and help shippers and logistics companies choose more efficient carriers and reduce their transport carbon footprint. SmartWay provides tips on efficient driving, including speed awareness and turning off idling engines.

More Information: http://www.epa.gov/smartway.

6.3.3.3. Best Workplaces for Commuters

The Best Workplaces for Commuters program was first established in 2001 by the EPA and the DOT to promote innovative solutions to commuting challenges faced by employers and employees. The program provided tools, guidance, and promotional opportunities to help U.S. employers incorporate commuter benefits into their standard benefits plan, reap financial benefits, and gain national recognition. In October 2007, the University of South Florida's Center for Urban Transportation Research assumed management of the program.

More Information: http://www.epa.gov/oms/bwc.htm and http://www.bestworkplaces.org/.

6.3.4. Regulatory Measures

6.3.4.1. Transit Benefits

Employers were allowed to provide workers with up to $230 per month in tax-free transit and vanpool benefits in 2011. The monthly aggregate exclusion amount limitation under Section 132(f)(2)(A) Qualified Transportation Fringe Benefits for vanpools (commuter highway vehicles) and transit passes was $230. The monthly exclusion amount limitation under Section 132(f)(2)(B) for qualified parking also was $230. Commuters could receive both transit and parking benefits (i.e., up to $460 per month). Employers could allow employees to use pretax dollars to pay for transit passes, vanpool fares, and parking (National Center for Transportation Research 2011). The transit and vanpool benefits routinely expire and must either by renewed by Congress or roll back to a level of $125 per month; most recently they expired at the end of 2011, although actions appear to be underway to restore benefits. In contrast, the parking benefit increased to $240 as of January 2012.

6.3.4.2. Government Employee Telework Enhancement Act of 2010

The Telework Enhancement Act of 2010 was enacted to promote teleworking within federal government agencies. Supporting the Act is a *Guide to Telework in the Federal Government* that outlines practical information to assist federal agencies, managers, supervisors, and telework managing officers in setting expectations for teleworking.

More information: http://www.telework.gov.

6.4. Other Potential Federal Actions

This section discusses other potential actions that the federal government could take to promote travel reduction and efficient driving, and this report does not advocate for or against these strategies. These actions may take a variety of forms, including:

- Technical and planning assistance to transportation or other agencies, e.g., through the publication of resource documents, tool kits, case studies, and models, or conducting peer exchanges
- Education, marketing and outreach directly to the general public
- Funding directly targeted at specific strategies (e.g., transit, nonmotorized, TDM programs, land-use planning), or provided on a performance basis (e.g., incentives or disincentives tied to VMT reduction targets)
- Tax policy, including tax-exempt benefits; direct implementation of transportation funding mechanisms, such as a VMT fee, carbon tax, or increase in the gas tax; or tax credits (e.g., for employers or employees for AWS)
- Regulations targeted at states on topics, such as adoption of mileage-based insurance, anti-idling laws, and speed limits.

Research and demonstration projects, especially for new/emerging strategies for which implementation methods and benefits are not widely documented, are another role that the federal government can play. Section 7.0 focuses specifically on research needs and potential opportunities for DOE involvement in research on these strategies.

Examples of past and current actions for each type of action are shown in Table 6.1.

Table 6.1. Examples of Federal Actions by Type

Type of Action	Examples
Technical and Planning Assistance	Guidelines for Travel Demand Analyses of Program Measures to Promote Carpools, Vanpools, and Public Transportation (FEA) TCM Information Documents (EPA) TDM International Scan (FHWA) TDM Model (FHWA) COMMUTER Model (EPA)
Education and Marketing	Best Workplaces for Commuters (EPA) "It All Adds Up to Cleaner Air" campaign (EPA) http://www.fueleconomy.gov (EPA/DOE)
Funding for Projects, Programs, and Plans	CMAQ Program (FHWA) Transportation Enhancements Program (FHWA)
Tax Policy	Pretax commuter benefits
Regulation	CAAA/Transportation Control Measures and Transportation Conformity Requirements (U.S. DOT/EPA implementation) 1974 National 55-mph speed limit

Table 6.2 presents an "opportunity matrix" that organizes the strategies by comparing federal authority versus potential payoff. Strategies shown in italics are those for which an existing federal agency (in most cases the U.S. DOT, and in a few cases the EPA) is already taking an active role in implementation.

Table 6.2. Opportunity Matrix for Travel Reduction and Efficient Driving Strategies

	Potential Payoff[a]		
Federal Authority	**Low (<0.5%)**	**Medium (0.5%-1.0%)**	**High (>1.0%)**
High	*Idle reduction*	*Transit improvements* *Nonmotorized improvements*	*Pricing (VMT or carbon fee)*
Medium	Education and Marketing campaigns *Real-time traffic information* *Real-time transit and multimodal information*	*Pricing (congestion)* Employee commute options Ridesharing/vanpooling	Pricing (PAYD insurance) Eco-driving Speed limit reduction/ enforcement
Low	Parking management Carsharing	Telework/alt work schedules	

[a] Percentage shown for each column is estimated range of energy or GHG reductions expressed as a percentage of total on-road energy and GHG. See Table 6.1 for specific estimates for each strategy. Strategies shown in italics are those for which a federal agency is currently taking an active role in working to implement.

Table 6.3 provides a summary of some additional activities the federal government could potentially undertake to promote the strategies discussed in this report. Many of these are identified in U.S. DOT (2010c). The table also characterizes each strategy according to three factors that may affect how large a role the federal government may wish to play in promoting the strategy. These factors are:

Technological maturity:

- High – Well-developed and widely applied
- Medium – Examples of real-world deployment, but still not tested in a full range of circumstances
- Low – Only a few pilot examples or not yet deployed.

Potential payoff (the magnitude of additional energy and GHG reductions that may be achieved through the strategy):

- High – >1% reduction in on-road GHG possible
- Medium – 0.5%–1.0% reduction in on-road GHG possible
- Low – Less than 0.5% reduction in on-road GHG likely.

Federal implementation authority:

- High – Federal government currently has the authority to play a strong role in implementing strategy through funding and/or policy/regulation
- Medium – Federal government may play a role in implementing strategy, but has limited authority
- Low – Federal government currently has very limited funding or policy/regulatory authority. (This does not preclude involvement in the strategy through research and education.)

Table 6.3. Strategy Assessment and Federal Policy and Program Options

Strategy	Technological Maturity	Potential Payoff[a]	Federal Implementation Authority	Federal Policy and Program Options	Current Federal Activity
Travel Reduction					
Pricing					
PAYD Insurance	Low	High	Medium	Federal requirement that states require (or at a minimum, allow) insurers to offer mileage-based insurance	U.S. DOT Value Pricing Pilot Program could fund demonstration projects (but has not)
VMT or Carbon Fee	Low	High	High	Establishment of national VMT fee, carbon fee, or requirements or incentives for state-level implementation	Strong U.S. DOT and state DOT interest in VMT fees as alternative revenue source
Congestion Pricing	Medium/ Low[b]	Medium	Medium	Requirements or incentives for metro-level implementation (e.g., as part of transportation reauthorizing legislation)	U.S. DOT promoting through Value Pricing Pilot Program
Transit Improvements	High	Medium	High	Funding for transit investment and services	Federal transportation reauthorization (Congress) will determine transit funding levels
Nonmotorized Improvements	High	Medium	High	Funding for bicycle/pedestrian projects Requirement for states to adopt complete streets/ design policies for alternative mode accommodation	Federal transportation reauthorization (Congress) will determine program categories available for NMT and funding levels Otherwise, states and MPOs have discretion over use of transportation funds FHWA promoting Complete Streets policies
Parking Management	Med	Low	Low	Transportation funding incentives to support regional and local planning for efficient land use (including parking)	
Worksite Trip Reduction/ Employee Commute Options	High	Medium	Medium	Funding for regional employer outreach and commuter support programs Expanded tax incentives for alternative commute measures (telework, transit subsidies, etc.) Federal requirement for states to implement employer trip reduction ordinances	Primarily through FHWA CMAQ program funding
Telework and Alternative Work Schedules	High	Medium	Low	Tax incentives for telework or alternative work schedules provision Government lead by example	GSA programs already in place to promote telework and AWS for federal employees

Strategy	Technological Maturity	Potential Payoff[a]	Federal Implementation Authority	Federal Policy and Program Options	Current Federal Activity
Ridesharing and Vanpooling	High/Low[c]	Low/Medium	Medium	Funding for regional ridesharing and vanpooling programs	Primarily through FHWA CMAQ program funding
Carsharing	Med	Low	Low	Seed funding for carsharing study and deployment in emerging markets	
Education and Marketing Campaigns	High/ Low[d]	Low	Medium	Funding for individualized marketing programs	U.S. DOT/EPA fuel economy information EPA clean air campaigns
Real-Time Multimodal Information	Low	Low	Medium	Funding for project implementation, technical support, and institutional coordination to expand intelligent transportation systems	Ongoing funding for general ITS demonstration and deployment initiatives through U.S. DOT ITS Joint Program Office States have discretion to use federal transportation funding for ITS activities
Efficient Driving					
Real-Time Traffic and Parking Information	Med (Traffic) Low (Parking)	Low	Medium	Funding for project implementation, technical support, and institutional coordination to expand intelligent transportation systems	Ongoing funding for general ITS demonstration and deployment initiatives through U.S. DOT ITS Joint Program Office States have discretion to use federal transportation funding for ITS activities
Eco-Driving	Low	High	Medium-High	Requirements for auto manufacturers to incorporate in-vehicle fuel efficiency feedback and technology (e.g., tire pressure monitoring systems) Requirements for states to teach eco-driving practices in driver training and drivers' manuals Funding for eco-driving education	U.S. DOE and EPA – http://www.fueleconomy.gov EPA SmartWay program (truck fleets)
Idle Reduction	High	Low	High	Federal anti-idling law Funding for truck stop electrification	Promotion of voluntary efforts through EPA SmartWay program
Speed Limit Reduction/ Enforcement	High	High	Medium	National speed limit with incentives for state enforcement	

[a] See Table 6.2 for quantitative benchmarks for "potential payoff."
[b] Congestion pricing: "medium" for facility-specific only, versus "low" for area-wide.
[c] Ridesharing: "high" for traditional commute ridesharing, "low" for dynamic ridesharing.
[d] "High" for mass marketing, "low" for individualized marketing.

7. Additional Research and Analysis Needed

One possible federal role in promoting energy savings through travel reduction and efficient driving is through research and analysis to better understand the effects of different strategies or to overcome barriers that may exist to deployment. Based on Cambridge Systematics' expertise, this section discusses research needs for each strategy and identifies the potential opportunity for DOE and other federal involvement, considering gaps in knowledge and other activities underway. This report does not advocate for or against filling these research gaps, but is intended only to identify them.

Table 7.1 presents an overview of research needs by strategy. Major recent and ongoing research initiatives directed at the strategy are identified. The table then presents an assessment of the extent to which knowledge gaps are barriers to implementation, as well as an assessment of the potential opportunity for involvement in research.

This assessment has reviewed research on most if not all types of travel reduction and efficient driving strategies, but does not represent a comprehensive review of research needs or ongoing research activities for any one strategy. Before identifying specific research actions on any given topic, a more thorough review would be needed of recent, in-progress, and planned research.

In addition to these research needs, gaps in primary data collection can hinder efforts to plan for and evaluate travel reduction and efficient driving strategies as well as other transportation options. The nation is in a time of transition in travel behavior, with younger generations expressing different patterns and preferences than in the past. Methods for collecting data are also changing. The widespread migration to mobile phones and use of the Internet is making it easier to collect certain types of data (such as vehicle speeds) and data from populations that own GPS-enabled mobile devices, but it is also making random sampling of the entire population more difficult because many households no longer have "land line" telephones with numbers included in published listings.

Table 7.1. Research Needs by Strategy

Strategy	Research Need	Recent and Ongoing Research	Extent to Which Knowledge Gaps are Barriers to Implementation	Opportunity
Travel Reduction				
Pricing				
PAYD Insurance	Evaluations of pilot implementation efforts – working with private insurers Consumer implications (including equity) if implemented in specific states	A few research or pilot studies led by states, MPOs, and/or private sector (e.g., Massachusetts and Dallas, Texas)	Medium/High – Research needed on state-by-state basis to explain benefits and impacts to public, if strategy is to be widely accepted	High
VMT or Carbon Fee	Assessment of response to pricing under different conditions (urban context/form, transit availability, pricing levels, etc.)	A few federal/state-funded pilot studies (Minnesota, Oregon)	Medium/High – Need better understanding and addressing of equity issues, also privacy issues for VMT fee	Medium – U.S. DOT has funded some research on VMT fees
Congestion Pricing	Refined modeling of area-wide pricing to account for range of responses (e.g., time of day, by income level) Evaluation of potential impacts in range of metro areas	Most research to date focused on facility-specific evaluation SHRP 2 C10, Partnership to Develop an Integrated, Advanced Travel Demand Model and a Fine-grained, Time-Sensitive Network, TMIP activities to develop/ demonstrate more refined modeling methods	Medium/High – Need better understanding and addressing of equity and privacy issues	Medium – U.S. DOT has funded some research
Transit Improvements	Marginal impact of service improvements in different contexts (land use, fuel pricing, etc.)	Transit Cooperative Research Program Project (TCRP) H-42, An Exploration of Fixed-Guideway Transit Criteria Revisited, is relating ridership/productivity to urban form variables Should review TCRP research needs statements	Low – Primary barrier is funding	Low
Nonmotorized Improvements	Better data collection for monitoring and analysis Improved forecasting methods	Data collection improvement efforts underway by FHWA, NCHRP, Institute of Transportation Engineers; but funding will be needed to implement NCHRP Project 8-78 focusing on improved forecasting methods	Probably low – Funding and public support more of an issue	Medium – Research in this field is underfunded, additional research contributions likely to be welcomed
Parking Management	Destination choice impacts of parking pricing/management, and effects on overall travel in different contexts, as well as localized economic impacts		Low – Political acceptability much more of a concern	Low/Medium – Some interesting research questions, but hard to find practical application at this point

Strategy	Research Need	Recent and Ongoing Research	Extent to Which Knowledge Gaps are Barriers to Implementation	Opportunity
Work Site Trip Reduction/Employee Commute Options	Response to TDM initiatives in different geographic contexts and fuel price scenarios	Widely studied in 1990s, and in new TCRP Report 95 Ch. 19 (Evans and Pratt 2005) Data available from TDM programs with reporting requirements in Arizona, California, and Washington – has been used by Center for Urban Transportation Research for model development/analysis	Low – Primary challenge is getting employer/worker interest when there is not a compelling need (congestion, travel costs, etc.)	Low/Medium – Challenge to collect data – possibly could mine existing databases to look at geographic or temporal changes in response
Telework Schedules (TW) and Alternative Work Schedules (AWS)	Potential "saturation" market for both TW and AWS, and how it might vary under different fuel price scenarios (reflecting both employee and employer interest/acceptance) How job and personal/household characteristics interact to respond to different work schedules Long-term relocation impacts of TW and travel/energy benefits	A few local/regional surveys (e.g., Arlington, Virginia, and Phoenix) Some academic research focused primarily on TW	Low – Implementation has mostly been private sector initiative, little effect seen from public sector programs (except for agencies' employees)	High – Could do more comprehensive employer and worker surveys – but benefit is primarily for gaining better understanding of potential long-term impacts, rather than addressing implementation issues
Ridesharing and Vanpooling	Ridesharing response with respect to fuel price, program support (by employment cluster size, job type) Surveys and pilot studies to better understand interest in and market for dynamic ridesharing and response to fuel price changes	Studied extensively in 1970s, less recently	Low for traditional ridesharing High for dynamic ridesharing – currently in experimental phase	Medium – Dynamic ridesharing being investigated by private sector, but funded surveys/market research would help
Carsharing	Develop parameters to relate carsharing to land-use/transit characteristics; extrapolate for nationwide market and energy/GHG benefits Effects of carsharing as a supporting factor to increase transit ridership	TCRP Report 108 and other recent studies have evaluated carsharing (Millard-Ball 2005)	Low – Private sector is leading deployment	Low – Market will evolve over next few years
Education and Marketing	Study individualized marketing in different urban contexts; extrapolate effectiveness and program needs to United States	A few pilot studies undertaken in various cities, funded by FTA, public health groups, CMAQ	High – Need better information on effectiveness/response for individualized marketing in different contexts	Medium/High (Note – research requires pilot implementation funding)
Real-time Multimodal Information	Research on how real-time information (and other transit quality of service factors) may affect ridership in different contexts (geographic, pricing, etc.)		Medium – Deployment likely to occur anyway, but could benefit from quantification of benefits	Medium – Unmet need, but payoff may not be large and probably difficult to measure

Strategy	Research Need	Recent and Ongoing Research	Extent to Which Knowledge Gaps are Barriers to Implementation	Opportunity
Efficient Driving				
Real-time Traffic and Parking Information	Potential impact and deployment costs and mechanisms for real-time parking information	Some research on traffic information through U.S. DOT AERIS program	Low (for traffic info) – Market-driven deployment in progress Medium (for parking info) – Quantification of benefits could help	Low (traffic info) – Already extensive U.S. DOT and private initiatives Low/Medium (parking) – Unanswered questions, but likely modest payoff
Eco-driving	Potential market penetration/market acceptance of driver feedback and guidance technologies; understanding of how to reach broad market; safety impacts; most effective tools and information for different driver markets	Some research sponsored through U.S. DOT AERIS program	Medium	Medium – Some research undertaken/underway, but more studies would be helpful
Idle Reduction	Potential market size and per-vehicle benefits of reducing short-term idling		Low – Primary challenge is enforcement and user acceptance	Low – Not a high-payoff topic
Speed Limit Reduction/ Enforcement	Information on benefits of speed reduction/enforcement at different levels and for different facility types Costs versus benefits to road users (including trucks and autos) at different fuel price levels		Low	Low – Primary barrier is public acceptance, rather than information
Cross-Cutting				
Interactions among strategies	Analysis demonstrating extent to which various strategies are more or less effective if applied in combination Analysis demonstrating effectiveness of strategies according to regional characteristics (total population, density, transit service, etc.)	A handful of regional modeling studies have examined interactions among transit, pricing, and land use ICF International (EPA 2011b) examined effectiveness of TDM strategies in regions with different population characteristics	Low	Medium – Improved information would help improve decision-making and selection of most effective strategies (and combinations) in different contexts Sophisticated modeling is needed to fully account for interactions
Improved sensitivity of planning tools to demand-side strategies	Development of model enhancements or post-processing procedures to incorporate additional TDM/driver behavior strategies into the existing regional travel demand modeling framework	Models have been enhanced in several areas of the country to better consider transit, nonmotorized travel, and pricing Other TDM measures are usually still considered off-model via sketch-plan tools	Low to Medium – Integration into the standard modeling framework could increase legitimacy of strategies	Medium – There are some research/demonstration needs, but to some extent the needs are to bring regional models in more areas up to the state of practice

TRB Special Report 304 (TRB 2011a) defined a sustainable national program of travel data collection and proposed a National Travel Data Program to carry this out. Funding, estimated at $150 to $200 million over the next decade, has not been identified. This would represent a sustained increase of $9 to $14 million per year over the current federal spending level of $6 million per year.

Elements of core data collection for passenger travel identified in TRB Special Report 304 include:

- A next generation *National Household Travel Survey* (NHTS) (U.S. DOT BTS 2012). Failure to continue this survey will likely create a major data gap. NHTS is conducted every five to eight years (most recently in 2001 and 2009), but at this time funding has not been identified for the next NHTS. NHTS is the only consistent nationwide source of travel behavior data, aside from the American Community Survey, which includes only work trips. Sample sizes in the NHTS are also too small to allow for detailed geographic analysis, unless a state or MPO purchases add-on samples (as 14 states and 6 MPOs did in 2009).
- An *intercity passenger travel survey*. Lack of data on long-distance travel, particularly automobile travel, is a major deterrent to evaluating transportation strategies such as high-speed rail that affect intercity trips. Aside from very limited information in the NHTS and the American Time Use Survey, such information has not been systematically collected on a national basis since the 1995 American Travel Survey (NYSDOT 1995).
- A *national panel survey*, which would collect information on travel behavior from the same people and households over a multiyear period. This would provide a richer data set than is available through the cross-sectional data obtained with existing travel surveys.

Additional cross-cutting data gaps identified in the "Telework Trendlines 2009: A Survey Brief by WorldatWork" (WorldatWork 2009) report and relevant to the strategies discussed in this report include:

- *Transportation service and cost measures*. No data source provides detailed measures of transportation services and their costs for particular trips or movements, nor is there easy access to linked data describing available travel options.
- *System reliability*. Very limited data are collected on the reliability of passenger or freight services, a critical element of service quality.
- *Travel behavior*. Considerable amounts of data are collected on travel movements, modes of transport, and even trip purposes. However, far less attention has been given to understanding what motivates travel for both individuals and firms.
- *Linkages to contextual data*. Travel data are poorly linked to data on nearby land use, activity densities, and availability of facilities that support nonmotorized travel.
- *Geographic specificity and low survey frequency.*

Other specific gaps identified by the authors of this report include:

- For pricing analyses, an important data gap is information on how people value time. Average values are fairly well understood, but the variations across such items as demographic groups and trip purposes are not. This is hard to derive from revealed-preference survey data, such as household surveys. Stated-preference surveys can be tailored to obtain this type of information, but in general such surveys would need to be specifically designed for this purpose. We also do not have a good understanding of how price changes break down into specific effects (mode shifting, time-of-day shifting, destination shifting, trip chaining, and elimination of trips).
- Lack of quality data on nonmotorized travel has long been a problem. Metropolitan travel surveys have been significantly improved in the past 10 to 15 years to capture walk and bicycle trips, but these modes may still be underreported. In addition, because most trips in most areas are by

automobile, oversampling of walk, bicycle, and transit trips is usually needed to gather sufficient data on these modes. Pedestrians and bicyclists also cannot be counted with the same technology used for motorists. Efforts by FHWA and professional groups are underway to improve nonmotorized data collection (National Bicycle and Pedestrian Documentation Project), but funding is still a major barrier, along with lack of standard protocols.

8. Conclusions

Wide Variations in Impact of Strategies to Address Travel Behavior

Estimated effects of individual strategies on surface transportation energy use and GHG emissions range from less than one percent to a few percent for the most aggressively implemented strategies. The wide range of findings on strategy effectiveness includes:

- Pricing that applies to all or a large fraction of travel, such as VMT fees or mandatory PAYD insurance, has the potential to be one of the most effective strategies, if it can be implemented in a way that is acceptable to the general public. Pricing will lead to a variety of responses, such as shifting modes, taking fewer trips, taking shorter trips, or combining trips for multiple purposes.
- In theory, ridesharing and eco-driving also have high potential; but in practice, it is difficult to achieve broad behavioral changes in the absence of strong incentives (such as high fuel prices).
- Reducing speed limits on highways can provide significant benefits for modest costs, as long as it is accompanied by strong enforcement. Better enforcement of existing speed limits can provide similar benefits.
- The potential for other strategies, applied individually, appears modest in the short- to medium-term (through 2030). However, there are important synergies among a number of strategies, such as land-use, transit, nonmotorized improvements, and road pricing. Over the long term (2030 to 2050), the combined effects of these strategies may be significant.
- Estimates of the combined impacts of travel behavior strategies, beyond actions that are already being implemented, typically range between 3% and 20% of either on-road or surface transportation emissions in 2030. This range of estimates reflects the inclusion of different strategies and assumptions regarding the level of implementation aggressiveness and potential shifts in behavior.

Many of these strategies are already being implemented to varying degrees—often for reasons apart from energy and GHG reduction, such as congestion relief, mobility/accessibility enhancement, and air quality improvement. For example, state, regional, and local transportation agencies have implemented rideshare programs, employer trip-reduction initiatives, and eco-driving programs to teach drivers to drive more efficiently. The non-pricing strategies with the greatest potential impact are also potentially the most difficult to implement, however, due to issues of public acceptance and related challenges in changing the behavior of a wide audience without strong pricing or regulation incentives. Political and financial support—not attainment of the maximum level of effect—limit current levels of implementation of most of these strategies.

Both Quantifiable and Nonquantifiable Factors Affect Travel Choice

Understanding the factors that affect travel choices is important to understanding the potential effects of efforts to influence travel. Travel time and travel cost are the best known and most studied factors contributing to travel decisions. People have both constrained incomes and time budgets that limit how much they travel. People place different values on different types of travel time (e.g., traveling in-vehicle vs. waiting time), and people with higher incomes tend to value time more highly relative to monetary costs. Strategies that increase the monetary cost of travel will generally affect lower-income travelers more than higher-income travelers, although equity impacts may be mitigated by investing in alternative modes or otherwise redistributing the benefits of pricing revenues (e.g., to reduce other taxes or fees). Travel time reliability, or the certainty of the traveler arriving at the destination on time, is also an important factor; for example, increasing the reliability of transit may help to increase ridership, even if average travel time is not reduced.

Nonquantifiable factors, often characterized as "taste" in economic literature, can vary substantially from person to person, so it can be problematic to assign a general rule on how they affect travel choice. Such factors include habit, comfort, convenience, information, social influence, and safety and security. These factors can play a role in establishing a pattern of modal shifts, for example, between auto and transit. While information provision can affect travel choices, its effect is limited due to several barriers, and it will generally have an impact only under favorable circumstances.

The trips generated and choices of mode are also dependent on socioeconomic and demographic characteristics, such as household income, vehicle ownership, and household size and composition. Market segmentation can be a useful tactic to help tailor travel reduction and efficient driving strategies and most effectively target different population groups.

A Variety of Tools Are Available to Model Travel Reduction, but Not All Strategies Can be Easily Modeled

Methods for predicting the impacts of travel reduction strategies on energy and GHG emissions can be grouped into four general categories:

1. Spatial or network-based travel demand forecasting models, including the four-step and activity-based travel demand models commonly used by MPOs and some state DOTs to forecast flows over a transportation network.

2. GHG inventory and policy analysis tools designed with a specific focus on estimating energy and GHG changes based on changes in travel and vehicle and fuel technology.

3. Other sketch-plan travel analysis tools, usually spreadsheets incorporating factors such as mode choice coefficients, elasticities, or case examples to predict behavioral changes. These tools focus primarily on trip reduction, VMT reduction or benefit-cost analysis outputs, but may also include fuel consumption and/or CO_2 emissions changes as outputs.

4. Energy and emission factor models, which are typically used in conjunction with travel models to translate travel impacts into energy and GHG impacts. These models may also be used on a stand-alone basis to assess the impacts of strategies that affect vehicle operating characteristics but not travel demand.

The universe of formal packaged tools for assessing travel reduction strategies, including energy and GHG impacts, is limited by the availability of robust data on strategy impacts and the extent to which key factors can be quantified. For strategies that network-based models cannot readily represent, sketch-plan tools focus on worksite-based TDM and ITS strategies. For other types of strategies, it is common for analysts to develop their own spreadsheet calculations using whatever data they can identify on the proposed strategies' market penetration and effectiveness, including elasticities (e.g., for pricing strategies) or case examples from research and demonstration studies.

The Federal Government Could Play Additional Roles in the Future

The U.S. DOT and DOE have both played significant roles in funding research and demonstration projects dating back to World War II. Greater involvement at the national level could help deliver even greater travel reductions, resulting in larger decreases in energy use and GHG emissions. Strategies that appear to have at least a moderate level of federal authority as well as a moderate potential payoff (at least 0.5% reduction in surface transportation energy and emissions) include:

- Pricing (vehicle miles travelled, carbon fee, congestion pricing, PAYD insurance)
- Employee commute options to promote ridesharing, vanpooling, transit, and AWS
- Transit and nonmotorized infrastructure and service improvements
- Eco-driving
- Speed limit reduction/enforcement
- Incorporating trip reduction and efficiency driving strategies into federal fleets.

Most of the policy and program options to implement these strategies are outside of the DOE's direct jurisdiction. However, support from the DOE for research and demonstration projects could provide improved information that federal, state, and local agencies may need to make decisions about a given strategy or to implement it most effectively. For example, researchers are just beginning to understand the potential impacts of emerging telematics strategies that make use of personal mobile devices and other information technology, such as real-time information on route options, modal options, efficient driving, and variable pricing.

Travel reduction and efficient driving strategies are described, their expected potential estimated, possible federal roles summarized, and potential additional research noted in Table 8.1. Such strategies could provide a small, but collectively substantial, contribution to reducing U.S. GHG and petroleum use in the transportation sector.

Table 8.1. Strategy Impacts and Opportunities

Strategy	Description	Percentage of On-Road Energy/GHG Reduction in 2030[a]	Federal Policy and Program Options	Research Needs
Pricing				
PAYD Insurance	Converting a significant portion of the essentially fixed cost of insurance to a marginal cost based on mileage	2.5% (if mandatory)	Federal requirement that states require (or allow) insurers to offer mileage-based insurance	Evaluations of pilot implementation efforts — working with private insurers Consumer implications (including equity) if implemented in specific states
VMT Fee	Charging drivers per mile of travel	1.0%–2.5% ($0.02–$0.05 per mile)	Establishment of national VMT fee, carbon fee, or requirements or incentives for state-level implementation	Assessment of response to pricing under different conditions (urban context/form, transit availability, pricing levels, etc.)
Congestion Pricing	Pricing roadway facilities when they are congested to reduce traffic on those facilities to an improved level of service	0.5%–1.1%	Requirements or incentives for metro-level implementation (e.g., as part of transportation reauthorizing legislation)	Refined modeling of area-wide pricing to account for range of responses (e.g., time of day, by income level) Evaluation of potential impacts in range of metro areas
Transit Improvements	New fixed-guideway urban transit, expanding spatial or temporal service coverage or service frequency of bus systems	0.4%–1.1%	Funding for transit investment and services	Interactions with other strategies, i.e., how impacts of service improvements differ in different contexts (land use, fuel pricing, etc.)
Nonmotorized Improvements	Capital investments in nonmotorized infrastructure or supporting activities (e.g., parking) to encourage bicycling, walking, and other forms of nonmotorized transport	0.3%–0.8%	Funding for bicycle/pedestrian projects Requirement for states to adopt complete streets/design policies for alternative mode accommodation	Better data collection for monitoring and analysis Improved methods for forecasting impacts of improvements on nonmotorized travel
Parking Management	Changes to parking supply, pricing, or other management techniques to create disincentives to driving	0.3%	Transportation funding incentives to support regional and local planning for efficient land use (including parking)	Destination choice impacts of parking pricing/ management, and effects on overall travel in different contexts, as well as localized economic impacts
Work Site Trip Reduction/Employee Commute Options	Requirements for employers to reduce single-occupancy vehicle trips by their employees, or outreach, assistance, and incentive programs to encourage them to do so	0.2%–1.1%	Funding for regional employer outreach and commuter support programs Expanded tax incentives for alternative commute measures (telework, transit subsidies, etc.) Federal requirement for states to implement employer trip reduction ordinances	Response to travel demand management initiatives in different geographic contexts and fuel price scenarios

Strategy	Description	Percentage of On-Road Energy/GHG Reduction in 2030[a]	Federal Policy and Program Options	Research Needs
Telework Schedules (TW) and Alternative Work Schedules (AWS)	Reducing commute trips by using modern telecommunications and computer technology to work remotely, or by working longer but fewer days per week	0.9%–1.1%	Tax incentives for telework or alternative work schedules provision Government lead by example	Potential “saturation” market for both TW and AWS, and how it might vary under different fuel price scenarios (reflecting both employee and employer interest/acceptance) Long-term relocation impacts of TW and travel/energy benefits
Ridesharing and Vanpooling	Programs such as ridematching databases, vanpooling programs, and other supportive actions to increase vehicle occupancies for work trips	0.1%–2.0%	Funding for regional ridesharing and vanpooling programs	Ridesharing response with respect to fuel price, program support (by employment cluster size, job type) Surveys and pilot studies to better understand interest in/market for dynamic ridesharing and response to fuel price changes
Carsharing	A membership service offering access to a dispersed network of shared vehicles 24 hours, 7 days a week at self-service locations	0.1%–0.2%	Seed funding for carsharing study and deployment in emerging markets	Develop parameters to relate carsharing to land use/transit characteristics; extrapolate for nationwide market and energy/GHG benefits Effects of carsharing as a supporting factor to increase transit ridership
Education and Marketing Campaigns	Mass marketing and individualized marketing campaigns to provide people with information on the full range of travel options and impacts of their choices	0.3%–0.5%+[b]	Funding for individualized marketing programs	Study individualized marketing in different urban contexts; extrapolate effectiveness and program needs to United States
Real-Time Transit and Multimodal Information	Provision of up-to-date information on travel options, e.g., bus or train arrival and travel times	Unknown	Funding for project implementation, technical support, and institutional coordination to expand intelligent transportation systems	Research on how real-time information (and other transit quality-of-service factors) may affect ridership in different contexts (geographic, pricing, etc.)
Real-Time Traffic and Parking Information	Provision of up-to-date information on traffic conditions, incidents, parking, and availability of public transportation and other travel alternatives	0.1%+[b]	Funding for project implementation, technical support, and institutional coordination to expand intelligent transportation systems	Potential impact costs, deployment costs, and mechanisms for real-time parking information

Strategy	Description	Percentage of On-Road Energy/GHG Reduction in 2030[a]	Federal Policy and Program Options	Research Needs
Eco-Driving and Maintenance	Education programs directed at increasing vehicle fuel efficiency by affecting both driver behavior and vehicle maintenance	1.1%–5.0%	Requirements for auto manufacturers to incorporate in-vehicle fuel efficiency feedback and technology (e.g., tire pressure monitoring systems) Requirements for states to teach eco-driving practices in driver training and drivers' manuals Funding for eco-driving education	Potential market penetration/market acceptance of driver feedback and guidance technologies; understanding of how to reach a broad market; safety impacts; and most effective tools and information for different driver markets
Idle Reduction	Education, laws, and/or incentives to introduce technology to reduce idling of vehicles	0.1%–0.4%	Federal anti-idling law Funding for truck stop electrification	Potential market size and per-vehicle benefits of reducing short-term idling
Speed Limit Reduction/ Enforcement	Reduction and/or better enforcement of speed limits on freeways and rural highways	1.7%–2.7%	Establishment of national speed limit and/or incentives for improved enforcement of speed limits	Information on benefits and costs of speed reduction/enforcement at different levels and for different facility types

[a] Estimates from the literature as presented in Section 4.0, primarily based on U.S. DOT (2010c), which represents a synthesis of information from literature existing at the time that the report was developed (Urban Land Institute 2009). Moderate to substantial uncertainty is associated with most estimates. Provision of a point estimate rather than a range does not imply greater certainty.
[b] Denotes additional, unknown effect of emerging information technologies.

Appendix. Review of Literature

A.1. Overview

This literature review provides an annotated bibliography of references on the following topics:

- The travel, energy, GHG, and other costs and benefits of strategies to reduce personal vehicle travel
- The energy, GHG, and other costs and benefits of strategies to make travel more efficient, especially by affecting driver behavior. This review focuses on strategies directed at individual drivers and vehicles, rather than "system-level" operational strategies affecting traffic flow characteristics, such as traffic signal coordination.

The number of individual studies covering these topics is quite extensive. For example, it would be possible to reference substantially more than two dozen studies on telecommuting alone. This review therefore focuses primarily on sources that summarize and synthesize other research, rather than attempting to comprehensively review all studies. Because many of the synthesis studies cover both travel reduction and efficient driving strategies, no attempt is made to distinguish sources in the bibliography according to the types of strategies covered. Some studies on individual strategies are cited for emerging strategies for which information in published synthesis studies is missing or not up to date.

Although most of the literature sources presented here are from the past decade, some date to the 1990s. The older sources are included because they represented important literature syntheses at the time and still contain useful results. Much of the best research on TDM strategies was done in the 1980s and 1990s, and travel behavior findings in particular are still relevant. However, results from older studies need to be considered with caution since various factors affecting strategy effectiveness, such as new technology, fuel prices, congestion, have changed since the research was originally conducted.

The literature sources will serve as the basis for this report summarizing the following topics:

- The effects of travel reduction and efficient driving strategies, both individually and in combination, on VMT, energy use, and GHG emissions
- The costs and other benefits and impacts of these strategies
- Tools and methods available to quantify the impacts of these strategies
- Issues of uncertainty regarding market penetration, technology effectiveness, and traveler response
- Systematic obstacles to incorporating GHG and fuel savings strategies into the transportation planning process and ways around such obstacles

In addition to the published literature, the project team has conducted its own reviews of these strategies, as well as modeling techniques, for a number of clients in recent years and will draw on this experience in developing the this report.

A.2. Synthesis Documents and Multi-Strategy Studies

Apogee (1994). *Costs and Effectiveness of Transportation Control Measures (TCM): A Review and Analysis of the Literature.* Prepared for the National Association of Regional Councils.

This was an at-the-time comprehensive review of information on the effectiveness (measured in terms of VMT, trips, and pollutant emission reductions) and cost-effectiveness of a wide range of TCM. Both demand reduction and system efficiency strategies are included.

Cambridge Systematics, Inc. (Urban Land Institute 2009). *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions.* Urban Land Institute, Washington, D.C.

This report presents an analysis of the nationwide GHG reduction benefits and costs of system efficiency and travel behavior/VMT reduction strategies. Twenty-two individual passenger travel reduction strategies are included in the analysis. Cumulative GHG benefits (total and percent reductions), implementation costs, and driver cost savings over the 2010 to 2050 time period are estimated for each strategy and “snapshot” results are provided for 2020, 2030, and 2050. Equity implications are also assessed in general terms. The study found that a complete program of strategies could result in surface transportation GHG reductions in 2050 ranging from 4% to 18%, or as high as 24% under extremely aggressive deployment assumptions, when compared to a 2050 projected baseline that was slightly lower than 2010 levels. (The baseline assumed an annual 1.4% growth in VMT and a 1.9% improvement in fuel efficiency.)

Cambridge Systematics, Inc. and Eastern Research Group (NCHRP 2010). *Evaluate the Interactions between Transportation-Related Particulate Matter, Ozone, Air Toxics, Climate Change, and Other Air-Pollutant Control Strategies.* Prepared for NCHRP Project 25-25 Task 59.

This study assesses the effectiveness and cost-effectiveness of a variety of transportation emission control strategies at reducing emissions of various pollutants, including GHG, and identifies which strategies may reduce some pollutants while increasing others. A total of 34 control strategies are reviewed in three categories—TDM, transportation systems management (TSM), and vehicle and fuel technology. The study relies largely on information developed in support of the FHWA’s Congestion Mitigation and Air Quality Improvement Program (CMAQ), including two national CMAQ evaluation studies as well as evaluations conducted by state and regional agencies.

COMSIS Corporation et al. (FHWA and FTA 1993). *Implementing Effective Travel Demand Management Measures*. Prepared for U.S. Department of Transportation, DOT-T-94-02.

This report inventories TDM measures, reviews empirical information on their effectiveness and cost-effectiveness (both individually and packaged), and discusses implementation issues. It also describes the TDM Model, a software tool that is used to estimate the impacts of hypothetical scenarios (e.g., different levels of transit fare incentives) on vehicle trip reduction.

Energy and Environmental Analysis, Inc. (National Energy Technology Laboratory 2008). *Market-Based Approaches to Fuel Economy: Summary of Policy Options.* Prepared for National Energy Technology Laboratory, U.S. Department of Energy.

This report develops new national-level estimates of the energy-saving potential of market-based transportation energy reduction strategies, including: 1) vehicle pricing strategies with fees, rebates or subsidies based on fuel economy or vehicle technology; 2) highway pricing strategies for managing travel demand, including HOV/toll lanes; and 3) worksite strategies for reducing work trips, including transit incentives and parking cash-out. Policy issues are also discussed. Development of a network of HOV/toll lanes was found to reduce emissions between 0.1% and 2.5% in two test regions. Worksite strategies were estimated to have the potential to reduce emissions by 0.2% to 1.1% if applied nationwide.

Energy and Environmental Associates, Inc. and Cambridge Systematics, Inc. (U.S. DOT 1999a). *Greenhouse Gas Control Strategies: A Review of “Before-and-After” Studies.* Prepared for U.S. DOT, Federal Highway Administration.

This report includes a summary section on the impacts of TCM strategies, including site- and systems-based demand management as well as systems management, on VMT and GHG emissions. It includes a discussion of the history of TCM implementation. The report concluded that, based on implementation experience in the United States, area-wide, employer-based TDM programs, such as carpooling, vanpooling, supplemental transit, or nonmotorized incentives, could result in an overall reduction in SOV work-trip mode share on the order of 5%, which translates into VMT impacts for all trips at a regional level of less than 1%. The report notes that these results are consistent with evaluations of ridesharing programs conducted during the early 1980s, which also showed region-wide VMT impacts of less than 1%.

Federal Highway Administration (U.S. DOT 1998b). *Transportation and Global Climate Change: A Review and Analysis of the Literature.*

This study provides a synthesis of existing literature on travel reduction, fuel economy-focused, and alternative fuel (reduced-carbon content) strategies and potential ranges of VMT, fuel savings, and/or GHG impacts. Impacts are not expressed in consistent terms, but rather rely on the information available in the literature. The timing of benefits and implementation issues also is discussed.

Greene, Baker, and Plotkin (2011). *Reducing Greenhouse Gas Emissions from U.S. Transportation.* Prepared for the Pew Center on Global Climate Change.

This report examines the prospects for substantially reducing GHG emissions from the U.S. transportation sector. The authors conclude that it is possible to cut emissions cost-effectively by up to 65% below 2010 levels by 2050 by improving vehicle efficiency, shifting to less carbon intensive fuels, changing travel behavior, and operating more efficiently. Three scenarios are developed for improved transportation efficiency and reduced GHG emissions through 2050, with both technological progress and policy ambition increasing from the first to the third scenario. The three scenarios show GHG reductions of 17%, 39%, and 65% from 2010 emissions levels in the year 2050. The report includes reduction estimates for seven individual passenger travel reduction/efficiency strategies covered in this report (see Section 3.0). The report also discusses policies to promote mitigation and the roles of each level of government.

ICF Consulting (AASHTO 2006). *Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects*, requested by American Association of State Highway and Transportation Officials Standing Committee on Environment, prepared as part of National Cooperative Highway Research Program, Transportation Research Board, Project 25-25 Task 17.

This report identifies a total of 17 tools or methods that can be used to analyze the GHG implications of transportation projects and recommends models for transportation project or strategy analysis.

ICF International (EPA 2011b). *Potential Changes in Emissions Due to Improvements in Travel Efficiency.* Prepared for U.S. Environmental Protection Agency, Office of Transportation and Air Quality, EPA-420-R-11-003.

This study provides a national policy assessment of the potential of transportation control measures to reduce air pollution and GHG emissions. The study was based on travel demand modeling data and MOVES emissions analysis conducted for 15 metropolitan areas across the country and extrapolated to represent the United States as a whole. The strategies analyzed include TDM, land-use policies, transit fare reductions and service improvements, parking fees, and mileage-based fees. These were evaluated both individually and in combination using the Trip Reduction Impacts for Mobility Management Strategies (TRIMMS) model. CO_2e reductions from light-duty vehicles in 2030 were estimated to range from 0.1% for TDM only, to 3.4% for a combination of all strategies. Corresponding reductions in 2050 ranged from 0.3% to 8.8%. However, reductions for combined strategies ranged as high as 12% to 16% in some urban clusters.

International Energy Agency (IEA 2005). *Saving Oil in a Hurry.*

This report provides sketch-level estimates of fuel savings for a number of strategies that could be undertaken to quickly reduce oil consumption in the case of supply disruption. The study is internationally focused in terms of its data sources/assumptions, and estimates are provided for different regions of the world. Some cost-effectiveness estimates (expressed in $/barrel of oil) also are provided. For the U.S./Canada region, the following estimates are provided for percent of road transport fuel saved: 0.7% for free fares, 0.3% for service improvements, and <0.1% for bus-only/priority lanes; carpooling: 6.8% for infrastructure and programs or 1.0% for only programs; telecommuting: 4.4%; compressed (four-day) work week: 3.1%; 90 kph speed limits: 3.2%; eco-driving campaign: 5.0%. These estimates generally assume very aggressive strategy deployment.

Litman, T. (Victoria Transport Policy Institute 2011b). *On-Line TDM Encyclopedia*. Victoria Transport Policy Institute, Victoria, British Columbia. http://www.vtpi.org/tdm/.

This source provides a review and summary of benefits of a comprehensive set of TDM strategies. TDM strategies are reviewed in six categories: 1) improved transport options (26 strategies reviewed); 2) incentives to use alternative modes and reduce driving (15 strategies); 3) parking and land-use management (20 strategies); 4) policy and institutional reforms (11 strategies); 5) TDM programs and program support (16 strategies); and 6) TDM planning and evaluation. Each section includes a qualitative summary of travel impacts and various other benefits and impacts, as well as quantitative evidence on impacts where available.

Meyer (1997). *A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility* (1997). Prepared by the Institute of Transportation Engineers for the Federal Highway Administration, Washington, D.C.

An update of a report first published in 1987, this document provides information on costs, benefits, and implementation guidance for a wide range of TDM and TSM strategies.

PB Americas (2011). *Incorporating Greenhouse Gas Emissions into the Collaborative Decision-Making Framework: Draft Final Report.* Strategic Highway Research Program (SHRP) Project C09.

Among other things, this report includes a review of the literature on the cost-effectiveness and effectiveness (expressed in percent of transportation sector emissions) of a variety of transportation GHG reduction strategies, including VMT reduction, system operations, and vehicle and fuel technologies. The information in the report is primarily a synthesis of information from U.S. DOT (2010c) and Cambridge Systematics, Inc. (Urban Land Institute 2009). The report also provides an overview of modeling tools and methods available for estimating the impacts of transportation GHG reduction strategies.

RAND Corporation and RSG, Inc. (U.S. DOT 2012). *Reference Sourcebook for Reducing Greenhouse Gas Emissions from Transportation Sources.* Prepared for Federal Highway Administration, 2012.

This document reviews and summarizes literature on GHG mitigation strategies, including TDM, transportation system management, and vehicle improvement strategies. The document includes an assessment of GHG impacts, cost-effectiveness, data and tools, and implementation concerns. The assessment of GHG impacts is largely qualitative, illustrated by quantitative examples from specific projects or studies, rather than attempting to provide an apples-to-apples comparison across all strategies.

Rodier (2008). "Review of International Modeling Literature: Transit, Land Use, and Auto Pricing Strategies to Reduce Vehicle Miles Traveled and Greenhouse Gas Emissions," *Transportation Research Record* No. 2132, Transportation Research Board.

This article is a meta-analysis of multiple modeling studies undertaken by transportation planning agencies around the world. The study found that individual measures had relatively modest effects, but were more effective when combined. For example, land-use policy (19 studies) reduced VMT by a median 0.7% in 10 years and 1.7% in 40 years, while improvements in transit (9 studies) reduced VMT by a median 0.3% in 10 years and 1.0% in 40 years. However, combining land use and transit (34 studies) reduced VMT by a median 4% in 10 years and 16% in 40 years. Combining land-use, transit, and road pricing polices (15 studies) reduced VMT by a median 14% in 10 years and 24% in 40 years. The author also found that the largest relative impacts were found in the cities with the lowest initial density.

Transit Cooperative Research Program (various authors and dates). *TCRP Report 95: Traveler Response to Transportation System Changes* (TRB 2011c).

This report contains a series of chapters, published between 2003 and 2011, that review information on traveler response to a wide variety of transportation system changes. Two chapters deal with HOV and park-and-ride; five chapters deal with various aspects of transit service provision; three chapters deal with transportation pricing; three chapters deal with land use and nonmotorized travel; and two chapters deal with TDM, including parking and employer and institutional strategies. Each chapter includes an overview of the strategy, evidence on traveler response, underlying factors affecting traveler response, related information and impacts (including costs and energy and environmental relationships), case studies, and additional resources.

Transportation Research Board (TRB 2011b). *Policy Options for Reducing Energy Use and Greenhouse Gas Emissions from U.S. Transportation.* Transportation Research Board Special Report 307, National Academies Press, Washington, D.C.

This report contains an overview of the transportation policy landscape, factors driving modal energy use and emissions, and policy options to reduce transportation energy and GHG. It includes brief summaries of the potential for curbing private vehicle travel, including encouraging personal travel by means other than private vehicles and pricing parking and road use.

U.S. DOT (2010c). Transportation's Role in Reducing U.S. Greenhouse Gas Emissions. Report to Congress.

This report presents a comprehensive summary of existing literature and some original analysis on the GHG impacts and cost-effectiveness of a full range of transportation strategies. The report covers a full range of strategy types for all transportation modes. The chapter on reduction in carbon-intensive travel activity includes sections on 19 strategies. Some individual study results are presented. Summary ranges (low-high) of nationwide effectiveness (CO_2e reductions in 2030) and cost-effectiveness are presented for each strategy. The report also discusses other benefits of each strategy as well as issues affecting feasibility.

A.3. Emerging Strategies

This section presents information on emerging strategies to reduce travel and improve travel efficiency through information technology, including mobile devices such as tablets and smartphones, as well as information and communications infrastructure. In each case, technology is used either to enhance the effectiveness of an existing concept (e.g., smartphone applications to provide driver feedback for eco-driving) or expand the concept to new applications (e.g., use of mobile devices for dynamic ridesharing). Because these strategies are in the early stages of development, definitive information on their effectiveness does not yet exist. This section reviews studies that have attempted to quantify potential benefits and examples of tools and applications (apps) for each strategy that are currently on the market. The following types of strategies are considered:

Dynamic Ridesharing – Ridesharing that is arranged in or near real time (e.g., day of or night before), in contrast to traditional carpool arrangements with regular schedules. Dynamic ridesharing allows the market for ridesharing to be expanded beyond work trips and other regularly scheduled trips, to one-time trips.

Real-Time Traveler Information – Providing information to travelers shortly before or even during a trip on travel conditions (e.g., travel times, wait times) and options (e.g., mode, route) for the trip. Traveler information may be mode-specific or multimodal.

- Highway/Traffic – Although real-time traffic information has been implemented for over two decades via radio, telephone, and message signs, it is now becoming more accurate, comprehensive, and readily available thanks to web-enabled and GPS-enabled mobile devices. Traffic information can reduce energy and emissions by facilitating route-shifting (to less congested routes) or allowing travelers to delay or reschedule trips.
- Transit – A growing number of transit agencies are releasing real-time data on the locations of their vehicles and disseminating predicted arrival times via the web, mobile device applications, and message signs at transit stations. Improved transit information may attract travelers to transit by reducing uncertainty associated with vehicle arrival and travel times.

- Parking – Real-time parking information via mobile device applications can reduce VMT in searching for parking spaces and allow people to select alternative modes or destinations if parking is not available.
- Multimodal – A highly desired application of traveler information is multimodal information that identifies and compares all of the alternatives available to a traveler for a given trip in real time.

Eco-Driving – Eco-driving involves training drivers to operate their vehicle more efficiently, e.g., by reducing hard acceleration, reducing idling, and maintaining speeds within optimal ranges. With some technologies, control may be taken out of the hands of the driver (i.e., eco-adaptive cruise control). Although eco-driving public education campaigns (and feedback technology, such as upshift lights) have been implemented as far back as the oil crisis of the 1970s, new technologies provide the opportunity for real-time feedback on driving efficiency, as well as to link with infrastructure (e.g., prediction of signal timing and road grades) to allow for proactive rather than just reactive driving to minimize fuel use.

Much of the U.S. research on emerging applications is being funded through the Applications for the Environment: Real-Time Information Synthesis (AERIS) program, run by the U.S. DOT Research and Innovative Technology Administration (RITA). The program objective is to generate and acquire environmentally relevant real-time transportation data, and use these data to create actionable information that support and facilitate green transportation choices by transportation system users and operators.

A.4. Dynamic Ridesharing

Deakin, Frick, and Shively (2011). "Markets for Dynamic Ridesharing? Case of Berkeley, California." *Transportation Research Record* 2187.

This report assesses the potential for dynamic ridesharing in Berkeley, California, focusing on trips from the University of California to downtown Berkeley. The study employed data analysis for the downtown and campus markets, as well as focus groups of students and university employees. The researchers determined that about 20% of SOV commuters to campus who live in eligible areas would consider using dynamic ridesharing at least occasionally. Prospective users preferred to make ridesharing arrangements the previous evening. The report also posits that high-parking charges, limited parking availability, financial incentives, and carpool-parking subsidies enhance interest in ridesharing.

Levofsky and Greenberg (2001). "Organized Dynamic Ride Sharing: The Potential Environmental Benefits and the Opportunity for Advancing the Concept." Presented at the *Transportation Research Board 2001 Annual Meeting*.

This report reviews traditional versus dynamic ridesharing, discusses the potential environmental benefits of increased ridesharing, and analyzes organized ridesharing programs in Bellevue, Washington, and Los Angeles, Sacramento, Seattle, and Coachella Valley, California. The authors conclude that the deployment of technologies, such as cell phones and personal digital assistants (PDAs), could overcome past barriers to ridesharing and unlock latent demand.

Tools and Apps

Avego Driver (Avego Ltd. 2011). Free. Avego allows drivers to offer empty seats to prospective passengers along a route in real time.

Weeels (Weeels Inc. 2010). Free. This app enables users to share taxi or car service trips to similar destinations in New York City.

A.5. Real-Time Traveler Information

Highway Information

Note: Studies over the past two decades of the potential impacts of traffic information have often assumed widespread availability of information, as is now becoming the case. This section does not comprehensively review these studies as they have already been encapsulated in earlier summaries.

Güner, Murat, and Chinnam (2012). *Dynamic Routing under Recurrent and Nonrecurrent Congestion using Real-Time ITS Information.* Computers and Operations Research, Volume 39, Issue 2.

This study considers the value of dynamic routing in the context of "just-in-time" logistics. The authors propose new methods of incorporating the effect of recurring and nonrecurring delay in routing algorithms by utilizing available real-time traffic information. Tests on simulated highway networks were reported to show promising results.

SUNY Buffalo (University at Buffalo SUNY). *An Evaluation of Likely Environmental Benefits of Lowest Fuel Consumption Route Guidance.*

This ongoing research project through the AERIS program is investigating the potential environmental benefits of providing route guidance to travelers based on the lowest fuel consumption route.

Tools and Apps

Beat the Traffic (Triangle Software Ltd. 2011) (Free). This app offers real-time traffic speed and incident maps, information on traffic jams, incidents, and road work reports, and two-hour traffic predictions. It also allows the reporting of incidents to other app users.

INRIX Traffic (Inrix 2011) (Free). INRIX Traffic provides information on real-time traffic and traffic incidents, as well as best-time-to-leave predictions and comparisons with normal traffic patterns.

NAVIGON traffic4all (NAVIGON AG 2011) (Free). This app shows current traffic congestion and includes congestion forecasts. It highlights routes to avoid when planning trips and can be used with NAVIGON MobileNavigator for automatic routing.

Navigation by TeleNav – TeleNav GPS Plus (TeleNav Inc. 2011) ($0.99 first month, $9.99/year thereafter). This app provides voice activated GPS with live traffic guided routing to avoid traffic jams.

Waze GPS and Traffic (Waze Inc. 2011) (Free). Waze is a social driving app. In addition to offering real-time driving information, it allows drivers to share road information (incidents, congestion, etc.) with fellow Waze users.

A.6. Transit and Multimodal Information

Booz Allen Hamilton (U.S. DOT 2010b). *Real-Time Traveler Information Market Assessment White Paper*. Prepared for U.S. DOT Research and Innovative Technology Administration.

This report provides a comprehensive overview of perceived gaps in real-time traveler information across different modes (including highway, parking, and transit), identifies barriers to data collection, and offers suggestions for closing gaps. The report considers methods and current penetration of data dissemination, including changeable message signs, websites, smartphones, and telematics. The authors report that real-time data is available for only 39% of urban freeways (based on sensor coverage) and that automatic vehicle location systems are installed on 38% of transit vehicles.

Jones and Sloman (2003). "Encouraging Behavioural Change through Marketing and Management: What Can Be Achieved?" Presented at *10th International Conference on Travel Behavior Research*, Lucerne, Switzerland.

The authors posit that better information and persuasive marketing are important tools in convincing travelers to shift their travel behaviors to utilize more sustainable modes like transit and nonmotorized transportation. Among methods considered, the more widespread deployment of real-time public transportation information and targeted marketing is estimated to decrease car travel demand by 1.8% to 6.0% in urban areas of the United Kingdom. The authors note that the impact of bus information and marketing is difficult to isolate from the impacts of infrastructure improvements because the strategies are often implemented simultaneously (the figures reflect packages of both physical and information improvements and, according to the authors, slightly overestimate the contribution from information alone).

Mortazavi et al. (2009). *Evaluation of Displaying Transit Information on Changeable Message Signs Final Report*. CCIT Research Report UCB-ITS-CWP-2009-2.

This report summarizes the implementation of the Messaging Infrastructure for Travel Time Estimates to a Network of Signs 2.0 (MITTENS) changeable-message sign system. MITTENS 2.0 is able to dynamically generate highway travel times and comparative transit times for destinations to encourage transit ridership during peak hours. In a trial application in California, 4.9% of survey respondents said that they had shifted from automobiles to transit because of the travel information displayed on the signs. Of those who switched, almost 70% saved 20 minutes or more by taking transit. Low- and high-income drivers switched at a disproportionate rate as compared to drivers of average income. Validation of the MITTENS 2.0 system was focused on determining whether it would be advantageous for drivers to switch to an alternative route (i.e., from CA 154 to U.S. 101). Significantly longer average travel times with greater variability were observed on U.S. 101. Therefore, drivers were not expected to use variable message sign guidance to modify trip routes.

Taniguchi and Fujii (2007). "Process model of voluntary travel behavior modification and effects of travel feedback programs." *Transportation Research Record* 2010: 45-52.

This report considers the effect of travel feedback programs (TFP) in shifting travelers from automobile to transit or nonmotorized modes. It employs an integrated suite of theoretical behavioral models to predict behavioral shifts, which is then calibrated using survey data. The authors conclude that TFPs have positive effects on behavioral intentions and on implementation intentions, which are expected to result in reduced car use.

Usui et al. (2008). "Development and Validation of Internet-Based Personalized Travel Assistance System for Mobility Management." Presented at the 15th ITS Word Congress.

This study constructed a pilot program in Japan to reduce carbon emissions from driving by deploying a travel assistance system that incorporates GPS data collection, a personalized mobility planning tool, and a route guidance tool to allow users to select the fastest, least congested routes to and from work. The study participants reduced their baseline emissions from travel by 20%, primarily a result of switching to more environmentally friendly modes.

Tools and Apps

Froehlich et al. (2009). "UbiGreen: investigating a mobile tool for tracking and supporting green transportation habits." Prepared for CHI 2009.

This report presents the UbiGreen Transportation Display prototype, a mobile phone application that semiautomatically senses and reveals information on traveler behavior. This application has not come to market.

NextBus (NextBus Inc.). NextBus offers a compact version of its website for smartphone users that provides GPS-enabled, real-time location and arrival data for a variety of public and college transit systems across the country.

Smart Ride (Codemass Inc. 2011) (Free). This app provides real-time bus and train arrival times for a selection of transit agencies. It provides access to a list of nearby transit routes, GPS-based real-time arrival times, stop locations, and real-time vehicle delays. Currently includes LA Metro, MBTA, TTC, and AC Transit, among other urban and college transit providers.

A.7. Real-Time Parking Information

Mathur et al. (2009). "ParkNet: a Mobile Sensor Network for Harvesting Real-Time Vehicular Parking Information." Proceedings of the *2009 MobiHoc S3 workshop on MobiHoc S3*.

This report proposes systems architecture for sensing and disseminating parking availability in urban areas (dubbed ParkNet). The platform is based on ultrasonic sensors attached to public and private vehicles, which detect vacancies and relay information to users in real time. The authors cite previous studies that claim 45% of all Manhattan traffic is generated by vehicles circling and, in one small Los Angeles business district, cars seeking parking generated the VMT equivalent of 38 trips around the world in one year. However, the authors do not estimate potential VMT reductions enabled by the ParkNet system.

Rodier, Shaheen, and Kemmerer (2008). *Smart Parking Management Field Test: A Bay Area Rapid Transit (BART) District Parking Demonstration – Final Report.* University of California Partners for Advanced Transit and Highways.

This report contains early results from a test of advanced parking technologies at the Rockridge BART station. The system permits space reservations by Internet, mobile devices, and phones and employs traffic sensors that keep count of the vehicles in the garage. The real-time reservation and sensor data is then displayed on variable message signs to alert drivers of availability. The authors propose that the new parking system may have increased BART ridership due to greater ease of parking, but may not have resulted in automobile trip reduction due to diversions from carpool, bus, and bicycle modes.

T3 Design (U.S. DOT 2010a). "Automated Parking Information System Operational Test Evaluation for WMATA Glenmont Parking Facility." Prepared for the U.S. DOT Federal Transit Administration.

This report summarizes the results of a FTA-funded grant to pilot a system that informs commuters of parking availability at transit parking garages while they are en route. The project's test statement was that by informing commuters of full parking garages in advance of their arrival, it would allow the commuter to use nearby park-and-ride lots that are connected to the transit station by bus. An "acceptable" number of survey respondents bypassed the full garage and drove directly to one of the two potential park-and-ride lots after seeing the variable message sign, which reduced time and mileage spent seeking parking.

Tools and Apps

Park Circa (Park Circa Inc. 2011) (Free). Park Circa connects drivers looking for parking spaces with users who have underutilized private spaces.

ParkShark (StreamHire Inc. 2011) (Free). This app allows ParkShark users to locate on-street parking spaces being vacated by other ParkShark users.

Recargo (Recargo Inc. 2011) (Free) and CarStations (CarStations 2011) (Free). Both apps locate electric vehicle charging stations.

A.8. Eco-Driving/Driver Feedback

Note: This section includes only references published in 2008 or later. Older research on eco-driving has already been summarized in this report.

Ahn, Rakha, and Moran (2011). "Eco-Cruise Control Systems: Feasibility and Initial Testing." Poster presented at *Annual Meeting of the Transportation Research Board*, January 2011.

This study investigates a possible fuel saving and greenhouse emission reduction strategy using an eco-cruise control system. The eco-cruise control system employs adaptive cruise control integrated with road topography information. A study on a 45-km segment of I-81, which included uphill and downhill segments of up to a 4% grade, found a savings of 10.3% in fuel consumption and CO_2 emissions over the segment.

Barth and Boriboonsomsin (2009). "Energy and Emissions Impacts of a Freeway-Based Dynamic Eco-Driving System." *Transportation Research Part D: Transport and Environment*, Volume 14, Issue 6.

This report assessed the potential benefits of an eco-driving system designed to smooth driving patterns and reduce hard acceleration by providing drivers with real-time speed recommendations. The system was tested using the PARAMICS microscopic simulation software and a limited field study. The authors concluded that fuel consumption on congested freeway segments could be reduced by 10% to 20%, although the benefit would be negligible under free flow conditions.

Boriboonsomsin, Barth, and Vu (2011). "Evaluation of Driving Behavior and Attitude toward Eco-Driving: A Southern California Limited Case Study." Paper No. 11-0151, *Transportation Research Board Annual Meeting*, January 2011.

This study evaluated how an on-board eco-driving device that provides instantaneous fuel economy feedback affects driving behavior and the resulting fuel economy for gasoline engine vehicle drivers in Southern California. The results from 20 driver samples show that, on average, the fuel economy on city streets improves by 6% while the fuel economy on highways improves by only 1%. The low improvement on highways may partly be due to the mostly congested freeways in the study area, which already constrained the driving. According to responses to a questionnaire, the group of participating drivers were willing to adopt eco-driving practices in the near future. In fact, 40% of them have already practiced eco-driving, which may also be another reason for relatively low-fuel economy improvements. For this group of drivers, the eco-driving adoption rate could go up to 95% if the gasoline price increased above $4 per gallon.

Gonder, Earleywine, and Sparks (2011). *Final Report on the Fuel Saving Effectiveness of Various Driver Feedback Approaches*. National Renewable Energy Laboratory.

This report investigates driving behaviors and their potential impacts on fuel consumption. The authors estimate that fuel savings of 20% could be obtained by implementing efficient driving techniques on aggressively driven trips and 5% to 10% could be saved by those employing more moderate driving styles. The report also considers factors affecting drivers' decisions to adopt efficient driving methods in three categories: 1) acceleration/deceleration reduction and smoothing; 2) speed reduction/optimization; and 3) idle-time reduction. The authors then assess driver feedback approaches for effectiveness/workability and the likelihood of driver adoption. These approaches include prior education; real-time feedback through dashboards, smartphones, and on-board diagnostic devices; and offline feedback systems.

Morsink et al. (2008). In-Car Speed Assistance to Improve Speed Management.

This report assesses the potential benefits and impacts of using Intelligent Speed Assistance (ISA) and Advanced Cruise Control (ACC) systems to help drivers choose speeds. Based on simulation results, it is suggested that, when all vehicles are equipped with mandatory, dynamic, and automatic controlling ISA, emissions could be reduced by 4% to 11%.

Kamal et al. (2009). "Development of Ecological Driving Assist System: Model Predictive Approach in Vehicle Control." Presented at the *16th ITS World Congress*.

The authors propose development of an ecological driving assist system (EDAS) that utilizes real-time traffic information to provide drivers with eco-driving assistance based on anticipation of conditions ahead. The EDAS was tested using AIMSUN NG microscopic simulation software. Results suggest that the EDAS could reduce fuel consumption by 10%, particularly in urban settings.

Katsaros et al. (2011). "Performance study of a Green Light Optimized Speed Advisory (GLOSA) application using an integrated cooperative ITS simulation platform." Presented at the *Wireless Communications and Mobile Computing Conference (IWCMC), 2011 7th International*.

This study proposed a GLOSA and monitored its impacts on average fuel consumption and average stop time behind a light, using a single urban route with two traffic lights. The authors posit implementation of a GLOSA could reduce both fuel consumption and congestion.

Koukoumidis, Peh, and Martonosi (2011). "SignalGuru: Leveraging Mobile Phones for Collaborative Traffic Signal Schedule Advisory." Presented at *MobiSys 2011*.

SignalGuru uses a network of smartphones mounted on car dashboards to collect information about traffic signals and tell drivers when slowing down could help them avoid waiting at lights. By reducing the need to idle and accelerate from a standstill, the system saves gas. In tests conducted in Cambridge, Massachusetts, it helped drivers cut fuel consumption by 20%.

Virginia Tech Transportation Institute (2011a). "Developing and Evaluating Intelligent Eco-Drive Applications."

This project, funded through the AERIS program, developed a vehicle predictive eco-cruise control system to minimize fuel consumption based on roadway topographic information. The predictive eco-cruise control system consists of three components: a fuel consumption module, a power-train module, and an optimization algorithm. Results demonstrate fuel savings of up to 15%.

Virginia Tech Transportation Institute (2011b). "Eco-Speed Control Using V2I Communications."

This project, funded through the AERIS program, evaluated using signal phase and timing data (SPaT) to adjust driver speeds at signalized intersections. The study findings include a fuel consumption reduction of up to 50% within the vicinity of signalized intersections, with particular promise for larger-engine vehicles.

Tools and Apps

A Glass of Water (Toyota Sweden AB 2010) (Free). This app simulates a glass of water placed on the dashboard, promoting smoother driving (less hard acceleration and braking). Toyota claims that this app has the potential to lower fuel consumption by 10%.

GreenMeter (Hunter Research & Technology 2009) ($5.99). This app computes vehicle power and fuel usage characteristics and evaluates driving behaviors to increase efficiency and reduce fuel consumption and cost. Results are displayed in real time, while driving.

Green Driver (Green Driver Inc. 2011) (Free). Green Driver uses real-time traffic light data to avoid red lights, reducing hard acceleration and idling. Currently available for only Portland, Oregon.

goDriveGreen (Prologic Inc. 2011) (Free). This app is a GPS-enabled trip monitor that has a driving-efficiency calculator (acceleration, braking, and idling) and route and vehicle comparison features.

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