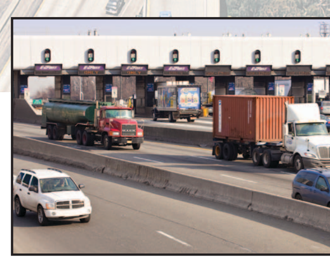
Potential Changes in Emissions Due to Improvements in Travel Efficiency - Final Report



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Potential Changes in Emissions Due to Improvements in Travel Efficiency

Final Report

Transportation and Regional Programs Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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Executive Summary

As transportation and air quality officials confront the contribution of the transportation sector to climate change, there is a growing interest in understanding the role travel efficiency strategies can have on reducing the impacts of travel on greenhouse gas (GHG) levels in the atmosphere. The impact of travel activity on total GHG emissions in the United States cannot be overlooked. Based on GHG emissions reporting for 2008, the transportation sector accounted for around 27 percent of the total U.S. GHG emissions. This represents the second largest source of GHG emissions, exceeded only by electricity generation. Since 1990 transportation has been one of the fastest-growing sources of GHG in the country, representing 41 percent of the total increase in GHG (EPA 2010a).

The Environmental Protection Agency (EPA), as well as state and local air quality and transportation agencies, has a strong interest in supporting efforts to reduce criteria pollutants as well as GHG emissions. Many criteria pollutants and their precursor emissions also impact climate, presenting "win-win" scenarios for climate and air quality when they are reduced (Shindell et al., 2008). The Transportation and Regional Programs Division (TRPD) of EPA's Office of Transportation and Air Quality (OTAQ) provides analysis, guidance and technical assistance on transportation policy and program effects on mobile source emissions and air quality to federal, state, and local agencies. These stakeholders are increasingly interested in understanding the effectiveness of the Transportation Control Measures (TCM) listed in the Clean Air Act (CAA) and other measures, such as road pricing and smart growth, to reduce emissions and vehicle miles traveled (VMT). The term TCM is used broadly in this report to include those travel efficiency measures listed in the CAA and other approaches for reducing VMT.

Strategies to reduce emissions also include operational measures that affect network speeds such as the application of intelligent transportation systems, speed limit controls, and the practice of eco-driving. These measures were not analyzed in this study because the methodology used in this analysis could not account for speed changes, upon which these strategies depend. There is also interest in understanding the various co-benefits resulting from these measures in addition to reducing emissions such as reduction in fossil fuel consumption, congestion, and accidents, which EPA will be exploring in a subsequent analysis.

The purposes of this report are to establish a reliable and useful source of information on the effectiveness of TCMs for changing travel activity and to quantify the potential national emissions reductions that could result from those changes using EPA's MOVES2010 emission model. This study is intended to support a national policy-level assessment of TCMs by using actual metropolitan planning organization (MPO) travel demand modeling results and examining their effectiveness at a national scale. The study focus is on light-duty vehicles and as such only considers gas and diesel fueled passenger cars and light duty trucks. The results therefore represent the reduction in urban VMT and emissions nationwide with rural travel assumed to remain unaffected. Although the analysis is based on actual travel data and characteristics of real metropolitan areas, the predicted changes to travel activity and resulting emissions from this analysis are not intended to represent the effectiveness of the TCMs for any particular area.

The strategies selected for analysis were: travel demand management (TDM), land use policies, transit-related strategies, and parking and road pricing. The strategies were further combined into future scenarios building from combinations of the most widely applied strategies to more aggressive approaches like transportation pricing. A sketch-planning tool developed at the University of South Florida, called Trip Reduction Impacts for Mobility Management

Strategies (TRIMMS), and the data from representative metropolitan regions were used to estimate the national potential for reductions in VMT under a variety of scenarios. Emissions Factors obtained from EPA's MOVES2010 (Motor Vehicle Emissions Simulator) model were then used to convert VMT reductions into emissions reductions. Recognizing that not all areas are currently willing to incorporate the complete range of TCMs in their transportation system, the application of the more aggressive TCMs, such as mileage fees, was limited to areas above a population threshold (>1.5 million). Key aspects of the study include:

- A review of recent studies to determine the range of effectiveness (in terms of elasticities and reported impacts) of various TCMs in addressing travel demand
- Development of an assessment methodology (**T**ravel **E**fficiency **A**ssessment **M**ethod, or **TEAM**), with input from a panel of subject matter experts
- Defining a set of future scenarios that incorporate various strategies expected to reduce travel activity and emissions
- Sketch-planning analysis of actual metropolitan areas representing a range of populations and transportation characteristics using available local data from regional planning organizations
- MOVES 2010 emissions modeling using results from the sketch-planning analysis of the surrogate metropolitan areas

In order to support the regional analysis using TRIMMS a number of decisions were required to account for incomplete or unavailable data. The decisions were guided primarily by current research and best practice observed in the metropolitan regions surveyed. Collectively these assumptions may result in an overall conservative result.

The time period for analysis and forecasting begins in 2010 with current year policies and develops through 2050. MOVES2010 was used to generate national-level, fleet-wide emission factors for this analysis reflecting emissions from start, refueling, and urban driving activities for years 2010, 2020, 2030, 2040, and 2050. These factors account for all changes incorporated in the model's default assumptions regarding vehicle technology and fuel characteristics. No additional strategies, including alternative vehicles and fuels or special use of retrofit technologies, were included.

The consistency of the results of this study with other similar studies, suggests that at the national level, understanding the potential for VMT reductions may be moving toward consensus. Although many factors contribute to the ability to reduce VMT and emissions, the interactions of the different strategies in different regional types suggest that it will be challenging to identify a single strategy or scenario that performs consistently across all metropolitan regions. The attractiveness of TCM strategies across all regions is that many of the technical and financial hurdles have been addressed; however, public opinion remains a challenge for some strategies, like pricing. The real determination of what works best in an individual region will be based on the willingness of the public and policy makers to support change. The present interest in addressing GHG and other aspects of climate change is supportive of these strategies. This study is intended to inform that interest.

As expected, the greatest benefit in emissions reduction results from a combination of effective strategies. The table below provides an overview of the potential reductions for each scenario evaluated for selected pollutants. The detailed results for reduction in VMT and emissions from this analysis are captured in Chapter 4 of the report and in the appendices.

Resulting Emissions Reductions for Selected Pollutants								
Scenario	Percent Emissions Reduction							
	2030				2050			
	CO_2 equivalent*	$PM_{2.5}$	NO_x	VOC	CO_2 equivalent*	$PM_{2.5}$	NO_x	VOC
1- Region-wide TDM	0.10%	0.10%	0.10%	0.09%	0.26%	0.26%	0.26%	0.25%
2 - TDM + land use changes	1.01%	1.01%	1.00%	0.98%	2.97%	2.96%	2.93%	2.86%
3 - TDM + land use changes + transit fare reduction	1.40%	1.40%	1.39%	1.36%	4.19%	4.18%	4.16%	4.08%
4 - TDM + land use changes + transit fare reduction + transit service improvements	1.44%	1.44%	1.43%	1.41%	4.30%	4.29%	4.28%	4.23%
5 - TDM + land use changes + transit fare reduction + transit service improvements + parking fees	2.92%	2.92%	2.91%	2.90%	6.98%	6.94%	6.87%	6.68%
6 - TDM + land use changes + transit fare reduction + transit service improvements + mileage fees	1.94%	1.93%	1.92%	1.87%	6.28%	6.25%	6.17%	5.95%
7 - TDM + land use changes + transit fare reduction + transit service improvements + parking fees + mileage fees	3.42%	3.42%	3.40%	3.35%	8.83%	8.78%	8.65%	8.29%

** CO_2 equivalent = [CO_2 + 21*(CH_4) + 310*(N_2)]*

Although this research is intended to illustrate the collective national impact of the different scenarios, the analysis may also be useful at the regional level in several ways. The most basic way for any region to use the study results is to compare travel characteristics from the input data and assumptions to existing regional model data in order to find a best-fit cluster for their area. The cluster-level results may prove informative on which strategies may offer the most potential to a real-world area. A second approach is to use specific model data from the region in TRIMMS to compare regional results to the study's cluster-level impacts. Those regions that are guided by the results may further validate the applicability to their specific region by using their travel demand model to test one or more scenarios. The input data and assumptions along with information collected from literature on elasticities will be helpful in establishing the modeling parameters.

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Chapter 1: Introduction

Since 1990 transportation has been one of the fastest-growing sources of greenhouse gas (GHG) emissions in the country; representing 41 percent of the total increase in GHG emissions. Based on GHG emissions reporting for 2008, the transportation sector accounted for approximately 27 percent of the total U.S. GHG emissions. This represents the second largest source of GHG emissions, exceeded only by electricity generation (EPA 2010a). The largest share of carbon dioxide emissions nationwide can be attributed to transportation (U.S. Department of Energy 2009). As Table 1 indicates, carbon dioxide emissions continue to grow significantly from 1990 well into the 21st century, despite the potential impacts of GHG emissions being widely acknowledged. While the percent growth is highest with respect to medium and heavy trucks and buses, light duty vehicles still contribute more total carbon dioxide emissions. The largest sources of transportation GHGs in 2008 were passenger cars (33%) and light duty trucks, which include sport utility vehicles, pickup trucks, and minivans (29%). Together with motorcycles, these light-duty vehicles made up about 63% of transportation GHG emissions (EPA 2010a).

Table 1. Transportation Greenhouse Gas Emissions by Mode, 1990 and 2008

	Carbon Dioxide	Methane	Nitrous Oxide
Percent change 1990–2008			
Highway Total	27.2%	-61.9%	-44.8%
Cars, light trucks, motorcycles	17.0%	-62.5%	-46.0%
Medium & heavy trucks and buses	67.9%	-50.0%	12.5%

Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008, Tables 3-12, 3-13, 3-14, April 2010.

The large-scale impacts of the transportation sector's emissions on global climate change have been gaining attention in recent years, as evidenced by initiatives from all levels of government to reduce trips and vehicle miles traveled (VMT). In 2000, the Federal Workforce Transportation Executive Order was passed, providing all federal employees in the National Capital Region a benefit equal to their commuting costs, not to exceed $65 per month (Executive Order 13150, 2000). In 2007, the Energy Independence and Security Act (P.L. 110-140, H.R. 6) was passed as an omnibus energy policy law designed to increase energy efficiency and the availability of renewable energy. In it, section 1131 increases the federal share for Congestion Mitigation and Air Quality Improvement Program (CMAQ) projects from a minimum of 80% of the project cost, to 100% of the cost. Section 1133 also states that while constructing new roadways or rehabilitating existing facilities, state and local governments should employ policies designed to accommodate all users, including motorists, pedestrians, cyclists, transit riders, and people of all ages and abilities. These initiatives, while focused on criteria pollutants, indicate that the federal government supports the numerous benefits accompanying more efficient travel, including improved air quality, corresponding health benefits and reduced congestion on the nation's highways. The U.S. Department of Transportation's (DOT) report to Congress in 2010, "Transportation's Role in Reducing Greenhouse Gas Emissions," provides the most recent overview of how transportation-related efforts may help reduce this impact.

At the state level California has taken the unprecedented step of establishing targets to reduce GHGs to 1990 levels by 2020. California's SB 375 directs the Air Resources Board (ARB) to set GHG reduction targets for regions of the state and to work with the metropolitan planning organizations (MPOs) to incorporate GHG reduction efforts into transportation, housing, and land use plans. The Assembly Bill 32 Scoping Plan adopted in 2008 contains regulations, incentives, voluntary actions and funding to reduce GHGs that contribute to climate change (AB 32, 2010). In 2007, the Oregon Legislature passed HB 3543, which set goals to reduce greenhouse gas emission to 75 percent below 1990 levels by 2050. Washington and Maryland have also passed similar laws to address climate change issues.

The term Transportation Control Measures (TCMs) refers primarily to the sixteen broad categories of strategies listed in Section 108(f)(1)(A) of the Clean Air Act (CAA) that are mostly aimed at reducing VMT and, therefore, emissions from travel activity. TCMs encompass both transportation systems management and travel demand management. The use of the term TCM in this report includes the travel efficiency related measures listed in the CAA and other VMT-reducing strategies, such as road pricing, not listed in the CAA. TCM are often considered for inclusion in State Implementation Plans (SIPs) for air quality and Transportation Improvement Programs (TIPs) for transportation conformity purposes and therefore have been widely used since the 1990s. The recognition of the contribution of the transportation sector to national GHG emissions has increased the level of attention on TCMs to reduce these emissions and on the techniques available to estimate and evaluate their effectiveness. As described, many states have begun to commit to targets for GHG emissions reduction through regional and state climate action plans and other initiatives. As a result, urban areas have increased their efforts to analyze the potential effectiveness of various TCMs. As the number of areas attempting to address GHG emissions from the transportation sector increases, there is a greater need to understand the effectiveness of TCMs. The purpose of this analysis is to quantify the effectiveness of VMT-reducing strategies in metropolitan regions in order to determine the potential for reducing VMT and emissions at the national-level.

Vehicle miles traveled represents a primary measure used by transportation professionals in identifying changes in travel behavior at any scale. It is also a required input into current emissions modeling and therefore has a defined relationship with emissions measurement. The Trip Reduction Impacts for Mobility Management Strategies (TRIMMS, version 2.0) model developed by the University of South Florida was selected for the analysis of TCMs in this study, after comparing several models that are available for this purpose (see Tables A-1 and A-2 in Appendix A for a comparison). TRIMMS is a sketch planning tool that relies on current understanding of price and travel time elasticities and synergistic effects of various strategies for analysis in order to estimate VMT changes resulting from defined future scenarios. The modeling results can be combined with emission factors from

> **Trip Reduction Impacts for Mobility Management Strategies (TRIMMS) model, version 2.0**
>
> *Description:* Spreadsheet–based sketch planning tool to measure travel impacts of regional and employer-based TCMs
>
> *Developer:* Center for Urban Transportation Research, University of South Florida
>
> *Updated*: 2009
>
> *Scale of analysis*: Site-level or regional
>
> *Inputs*: Average mode shares, trip lengths and travel times by mode, average vehicle occupancy, parking and trip costs by mode, and details about TCMs
>
> *Outputs:* Changes in mode shares, trips, VMT, and emissions; also benefits and costs and benefit-cost ratio (emissions and benefit-cost outputs not used in this analysis)
>
> *Methodology:* TRIMMS applies values of travel time and price elasticities for each mode based on a survey of empirical literature to calculate the reductions in VMT and trips. A baseline for VMT and trips is created from data input by the user and the reductions are calculated for a single year. Multiple strategies can be modeled simultaneously, capturing the combined effects. The values of elasticities can be changed by the user. TRIMMS also provides estimates of the reduction in emissions and does a benefit-cost analysis of the strategies that are applied. However, in this analysis, only the TRIMMS outputs of trips and VMT reductions were used.
>
> Guidance and model available on this link: http://www.nctr.usf.edu/spreadsheet/TRIMMS2.zip

EPA's MOVES2010 emissions model to provide the corresponding emissions for GHG and other pollutants.

> **Comparison of Present Analysis to Moving Cooler**
>
> The Moving Cooler report developed a range of scenarios (called "Bundles") to estimate the potential GHG emission reductions from travel efficiency strategies. The results from Bundle 6, which overlaps with many of the travel efficiency strategies in this analysis, shows a reduction in 2050 of 15% to 18% in GHG emissions. There are a number of reasons why this range is substantially greater than the reductions estimated in this report. The primary reason is that the Moving Cooler Report includes speed limit reductions, eco-driving and systems operation, multi-modal freight strategies, and management strategies, which were not modeled in the EPA analysis. These four strategies accounted for approximately 50 percent of the total Moving Cooler reductions. The different methodologies and assumptions for the baseline used by the two reports could also contribute to the differences. Excluding these four strategies, the results of the EPA analysis is generally consistent with the Moving Cooler report.

The research approach followed in this study began with a review of current findings from the literature. Several important research studies in recent years have attempted to quantify the potential of selected TCMs to reduce GHG emissions. Most notable are *Moving Cooler* (Cambridge Systematics 2009) and *Driving and the Built Environment* (Transportation Research Board [TRB] 2009). While *Driving and the Built Environment* addresses land development patterns and associated strategies, *Moving Cooler* considers a long list of TCMs and their potential effectiveness in reducing emissions. Both studies consider TCMs included in the present research, but were conducted using a significantly different methodology. Efforts to quantify the emissions reductions related to TCMs at the national level primarily rely upon meta-analysis of the findings from the collective body of research. In contrast, this study uses actual regional travel data from metropolitan regions varying in size and degree of transit use to analyze TCMs and their synergies with one another. Although comparison between the studies is limited by the difference in approach and specific assumptions, the results are similar and the review of previous studies provided an understanding of impacts that are reasonable to expect from different TCMs alone or in combination. In addition, several national experts were consulted for recommendations on the analysis methodology and the reasonableness of the study results.

Real data from MPO regions were used to arrive at a national estimate of VMT and GHG emission reductions using the following approach:

- Transit use and population variables were used to define seven different groups of metropolitan regions across the United States, called clusters.
- All metropolitan regions across the United States were assigned to the appropriate cluster based on their transit use and population. Two metropolitan regions from each cluster were selected as representatives for modeling purposes. Actual data were collected from the MPOs for each representative region.
- Using the real data from the representative regions, the effects of the different scenarios on VMT were modeled using TRIMMS. The model results from the two representative regions in each cluster were averaged together, resulting in an estimated reduction in VMT for individual regions in each cluster under each scenario.
- Emissions factors from MOVES2010 were used to determine the potential emissions reduction based on the estimated VMT reduction in each cluster under each scenario.

- The cluster values for VMT and GHG emissions were extrapolated to represent the entire cluster (the averaged values were multiplied by the number of regions in the cluster) and then summed across clusters to reach a national estimate.

Additional information about the selection of representative regions, the models used and definitions of the clusters is provided in Chapter 2. The following chapters provide a detailed discussion of each step of the study approach, the results and understanding of the lessons learned, and estimates of national emissions reductions under seven scenarios. Where limitations of the data and methodology could be improved to support regional analysis, it is identified throughout the report. The appendices provide the inputs and assumptions for the analysis along with other supporting information on modeling options and individual pollutant and GHG emission reduction.

Chapter 2: Consideration of Existing Research

The study began with a review of current national research on the effects of TCMs, smart growth, and other strategies for reducing GHG emissions. This included an evaluation of the available analysis tools, informed the selection of potential representative urban areas, and considered quantitative research on TCM efforts at the national, regional, and project level over the past decade. To obtain a broad understanding of current practices, the literature review took into account several major reports: *Multi-pollutant Emissions Benefits of Transportation Strategies* (FHWA 2006), *Growing Cooler* (Ewing et al. 2008a), *Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions* (Cambridge Systematics 2009). These reports were supplemented with evaluations of projects funded under the FHWA Congestion Mitigation and Air Quality (CMAQ) grants (FHWA 2008b), reports from the Transportation Research Board and the National Cooperative Highway Research Program, journal articles, regional planning studies and numerous conversations with regional representatives. A full list of resources is provided in the References section. A summary of the information gathered from existing research and how it informed the current study is provided in this chapter.

2.1 Recent Changes in Transportation Control Measures

As noted, a list of TCMs was included in the Clean Air Act. During the past decade new TCMs to reduce VMT have emerged. Road pricing is one of those emerging TCMs. Research indicates that the most common road pricing strategies implemented in the United States involve peak hour tolls and variable pricing on new and existing lanes. The conversion of High Occupancy Vehicle (HOV) lanes to High Occupancy Toll (HOT) lanes is one example. Other strategies, such as downtown congestion pricing, distance-based pricing, regional variable pricing, and pricing for heavy goods vehicles, have been implemented in countries around the world and are increasingly being considered by states and regions in the United States. A few experimental and pilot projects in the United States have introduced pay-as-you-drive insurance charges, mileage fees, variable parking pricing, and strategies such as parking cash-out. For instance, trials for mileage fees have been conducted in Oregon, the Puget Sound region, Minneapolis/St. Paul and Atlanta, and are currently in progress in six regions around the country as part of ongoing research by the University of Iowa. Parking cash-out programs are now authorized by state law in California. Under the U.S. DOT's Urban Partnerships Program and the Congestion Reduction Demonstration initiative, San Francisco, Miami, Seattle, Minneapolis/St. Paul, Atlanta, and Los Angeles, San Francisco and New York City are planning implementation of a variety of road pricing strategies including variable tolls on existing capacity, conversion of existing HOV lanes to HOT lanes, variable parking pricing and downtown congestion charging, combined in many cases with improvements to transit capacity. Pay-as-you-drive insurance has been legalized in some states, but has been implemented only on a small scale in the United States by a few private-sector insurance companies, including G.M.A.C. Insurance by General Motors, MileMeter, and GEICO Car Insurance. Massachusetts, Oregon, California, and Texas are some of the states promoting these programs.

An important impetus to the increasing focus on pricing-oriented TCMs in the United States has been the U.S. DOT's Value Pricing Pilot Program (VPPP). The program has been established to encourage states and local governments to test innovative pricing strategies, demonstrate their potential, and assess their effectiveness. The U.S. DOT has also recently established the *National Strategy to Reduce Congestion on America's Transportation Network.* Pricing strategies are a key element of this strategy, and are supported through the Urban Partnership Agreements in several metropolitan areas. Additionally, the need for alternative sources of revenues to build and maintain transportation infrastructure has created great interest in pricing programs around the country. Unfortunately, the need for transportation infrastructure improvements is outstripping the availability of funding from traditional revenue sources such as the Highway Trust Fund. A result of this funding shortfall is the broad consideration of innovative revenue sources including pricing strategies.

Another important recent change is that employer-initiated transportation demand management (TDM) programs are now being implemented in a more widespread way. State and local governments within Arizona, California, Maryland, New Jersey, Oregon, and Washington all have programs in place that work with major employers to provide financial incentives to encourage the use of alternative forms of commuting for employees, including transit benefits, parking cash-out programs, ride-matching programs, and alternative work schedules. Seattle's transit agency has developed one of the nation's first self-serve, public, internet-based rideshare matching services (VTPI 2008a). The State of Oregon, working with area employers, has set a target of a 10% commute reduction over three years and even has the ability to fine employers who fail to make a good faith effort to encourage employees to reduce automobile commute trips (VTPI 2008b). One Arizona MPO has adopted a mandatory travel reduction program for employers with 100 or more employees at a single site, which has led to significant annual savings in VMT, gas, dollars, and pounds of criteria pollutants (Pima 2007). The Philadelphia metropolitan area launched an Employer Trip Reduction program, which requires employers to meet vehicle occupancy targets for their employees by promoting trip reduction strategies. The variety of programs shows that different governments are picking and choosing programs that are adaptable in their region.

2.2 Efforts To Analyze Emissions Reductions

Several state and regional agencies, including state air quality, environmental, energy and transportation agencies, as well as MPOs, are taking steps to quantify transportation GHG emissions, despite the limitations of existing tools and uncertainties about how policy in this area will evolve. The ability to accurately estimate the emissions generated by current and future transportation systems, and the ability to estimate potential reductions in emissions from certain strategies is limited in most areas. In the absence of standardized tools and approaches, officials and planning agencies are relying on currently available methods to quantify GHG emissions or have begun developing new methods and tools that cater to their specific circumstances and needs.

California represents one of the most aggressive states in their efforts to address GHG emissions. California's SB 375 directs their ARB to set GHG reduction targets for regions of the state and to work with the MPOs to incorporate GHG reduction efforts into transportation, housing, and land use plans. In 2006, California's Global Warming Solutions Act (AB 32) established the goal of reducing GHG emissions to 1990 levels by the year 2020. Agencies that plan to conduct analyses on GHG emissions, or are developing analysis tools to do so, include statewide agencies and MPOs in California, Washington, Montana, and New York (FHWA 2008a). In 2004, Oregon's Governor's Advisory Group on Global Warming wrote the "Oregon Strategy to Reduce Greenhouse Gas Emissions" report, which recommended 84 specific actions that Oregon could take to reduce its GHG emissions. In 2007, the Oregon Legislature passed HB 3543, which sets goals to reduce greenhouse gas emissions to 75 percent below 1990 levels by 2050. It also establishes a Global Warming Commission, which will make recommendations to meet the GHG reduction targets. An advisory group followed up with the 2008 report "A Framework for Addressing Rapid Climate Change," which notes which of the 84 recommendations have been implemented, are currently in progress, and not yet implemented. State analysts estimate that Oregon is likely to meet its 2010 goal of arresting emission growth. In 2009, Maryland's governor signed into law the Maryland Greenhouse Gas Emissions Reduction Act of 2009, requiring the state to achieve 25 percent reduction in 2006 GHG emissions by 2020. Because of this law, Maryland DOT is responsible for addressing GHG emissions reductions in transportation and land use mitigation and policy options and will also work with other agencies on strategies such as Pay-As-You-Drive insurance and transportation technology improvements.

Several MPOs are leading efforts to improve the analysis capabilities in order to quantify GHG emissions as well as to improve modeling practices so that strategies can be more effectively analyzed. The San Francisco Bay Area MPO is conducting a preliminary analysis on proposed packages of investments to see if they will help reach their initial CO_2 emissions and VMT per capita reduction targets. Included in these packages are strategies such as rail transit, comprehensive road-pricing policy, and land-use policies based on smart growth principles. The Puget Sound Regional Council is using the U.S. EPA's Motor Vehicle Emission Simulator (MOVES) model to do a regional level analysis of GHG emissions in its long range transportation plan. Albany, NY's MPO has taken an innovative approach to the use of their travel demand model and based the region's calculated GHG emissions impacts on the assumptions that a range of policies and principles addressing transportation and sustainability will reduce trip generation per household by 15%, that there will be no new major highway construction, and that any widening will involve managed and HOV lanes. Sacramento Area Council of Governments has developed SacSim, the first activity-based travel demand model to use individual land parcels as the level of input data. This allows land use and transportation interactions to be more fully captured than travel demand models that use data aggregated at the traffic analysis zone (TAZ) level (SACOG Final Metropolitan Transportation Plan 2008).

From the literature review, it was determined that both pre-project estimates and demonstrated impacts at the project level can be found for some of the most common strategies that have been implemented to date. These include bicycle and pedestrian programs; ridesharing programs (including park and ride facilities); HOV/HOT lanes; carpool/vanpool programs implemented by individual employers or regional transportation management associations; improvements in transit marketing, information, and amenities; and some types of land use strategies. Impacts of pricing strategies such as parking pricing, parking cash out, conversion of HOV to HOT lanes, variably priced lanes, congestion pricing, and distance-based pricing, have been compiled from projects implemented under the federally-supported VPPP and from regional modeling studies.

The impacts of land use strategies on VMT documented in this report are based on a meta-analysis of over fifty recent studies (Ewing and Cervero 2010) and on data available from the *Growing Cooler* report (Ewing et al 2008a). These studies provide VMT reduction factors and elasticities for different types of land use strategies that have a significant effect on VMT only in the long term (TRB 2009; Cambridge Systematics 2009). These strategies are thus best implemented along with others that would have an impact in the short term.

TCMs have an impact on GHG emissions through four variables: change in number of trips (trip rates), change in vehicle miles traveled (trip lengths and overall VMT), change in highway mode shares (private passenger vehicles and transit), and change in vehicle speeds. The TCMs that have been implemented most frequently are at a local scale and lead to localized changes in the number of trips and VMT. These often do not have a significant effect on regional trips, VMT, mode shares, or speeds.

The TCMs that would result in a measurable regional reduction in automobile trips and VMT are those which affect regional mode share and speeds, and would consequently have the highest impact on regional emissions. These tend to be strategies involving regional transit expansion and service improvement, incentives for vanpools and carpools including construction of HOV/HOT lanes, and regional pricing strategies. For strategies that are implemented at a regional scale, impacts can be expected to be greater in larger regions where the absolute number of trips and VMT is larger. Even a small percentage reduction in regional VMT and automobile trips can potentially have a significant effect on regional emissions.

2.3 Impacts of TCMs and Elasticity Estimates from Literature

In order to narrow the list of TCMs for analysis, a range of quantitative estimates of the travel activity impacts of TCMs were compiled from several studies. The estimates identified which strategies have greater potential to reduce automobile trips and VMT, and would consequently have a higher impact on regional emissions (Cambridge Systematics 2009; Evans 2004; Evan et al. 2003; Ewing et al. 2008a; Ewing and Cervero 2010; FHWA 2008b; Johnston 2006; Litman 2010; Pew Center 2003; Rodier 2008; Shoup 1997; Small and Winston 1999; Pratt et. al. 2000; Vaca and Kuzmyak 2005). The ranges provided in Table A-3 in Appendix A show estimates of the change in automobile travel or transit ridership for a given change in user travel time or travel cost. For some types of strategies, such as employer-based programs and vehicle restrictions, specific estimated elasticities are not available in the literature but quantitative data on observed impacts from implemented projects and modeling studies can be considered. Where specific elasticities are not available, Table A-3 lists impacts in terms of percentage reductions in travel demand (trips or VMT). The elasticities shown in Table A-3 are travel demand elasticities, defined as the percentage change in travel (VMT or trips) caused by a one-percent change in user travel costs or travel time. In this study, travel costs are equivalent to out-of-pocket operating costs for auto drivers and passengers, and transit fares per trip for transit riders. For example, an elasticity of -0.5 with respect to fuel prices means that each 1% increase in the price of fuel results in a 0.5% reduction in vehicle mileage or trips. Similarly, transit service elasticity is defined as the percentage change in transit ridership resulting from each 1% change in transit service, measured in terms of headway or frequency. A negative sign indicates that the effect operates in the opposite direction from the cause (an increase in price causes a reduction in travel) (Litman 2010).

It is important to emphasize that although these ranges can provide an upper and lower bound on the impacts of various TCMs, the actual impacts on travel activity will differ by the particular characteristics of a region (density, size, transit availability), trip purpose, horizon year (long term or short term), and the other measures that would be simultaneously implemented. The values provided in Table A-3 represent the range of impacts of each TCM on travel activity. Where elasticity values were available and could be compared, the travel time and travel cost elasticities for each mode used in this study fall within the reported ranges shown in Table A-3. The actual direct and cross-price elasticities used in the analysis are provided in Tables A-4, A-5, and A-6 of Appendix A.

Note that Tables A-4, A-5, and A-6 provide values of direct elasticities and cross elasticities. Direct elasticities reflect the percentage change in the demand for trips of any given mode resulting from a change in that mode's price or other measurable service characteristics. Cross elasticities refer to the percentage change in the demand for trips of any given mode caused by a change in price or other measurable characteristics of other modes (Concas and Winters 2009, pp. 43-46). For example, an increase in peak period travel time or travel costs (e.g. parking prices) for autos causes a direct reduction in auto travel demand (negative direct elasticity) and an increase in transit travel demand (positive elasticity). Cross elasticities recognize and measure the potential degree of substitution or mode shift between transportation modes. The TRIMMS model uses default parameters compiled from a survey of empirical literature. More information about these values can be found in the guidance document available with the TRIMMS model (Concas and Winters 2009).

2.4 Tools Available for TCM Analysis

Methods for analyzing the effectiveness of TCMs have been developed with different capabilities and limitations. This following information considers the current modeling techniques, tools, and methods that were evaluated for use in this analysis. Table A-1 in Appendix A provides an overview of the input requirements and output capabilities of each tool. It also provides a more detailed assessment of each of the tools and discusses the key features, inputs, and outputs of those tools.

As the primary long range transportation planning tool, regional travel demand forecasting models are used for estimating the travel activity effects of infrastructure changes and land use plans at the regional scale. The review of studies and modeling practices undertaken for this study indicated that while some regions use a regional travel demand model for TCM analysis involving sub-areas, TCMs are routinely analyzed off-model using sketch planning methods, EPA's Commuter Model, or a broad range of spreadsheet-based tools because of their better sensitivity to TCM strategies. In addition, nuances such as changes in travel patterns due to pedestrian/bicycle facilities, transit-oriented development, and similar features are inherently difficult to model with regional travel demand forecasting models. Of the off-model tools used at the regional scale, spreadsheet-based sketch planning methods are most prevalent. Sketch-planning is often used in transportation planning to make high-level or preliminary decisions prior to detailed analysis or to narrow the range of options considered. For these reasons the sketch-planning approach was chosen as a reasonable way to assess the effectiveness of TCMs for changing travel activity.

Only two models that require detailed trip table inputs from regional organizations were identified: the Federal Highway Administration (FHWA) TDM Evaluation Model and the Surface Transportation Efficiency Analysis Model (STEAM), both developed by FHWA. The STEAM model is essentially a benefit-cost analysis tool that can also be used to analyze travel activity and emissions changes. In the 1990s, the FHWA TDM Evaluation model was used to evaluate TCM strategies and was a robust tool for that purpose. Although some studies still use this tool, it has not been updated since 1993. While the elasticities could be changed to reflect current trends in transportation demand, travel time, and strategy participation rates, the model does not take into account other important factors such as mode share for non-motorized transportation or fuel prices. Further, anecdotal evidence from practitioners at the local level indicated that the TDM Evaluation model is not widely used today. The STEAM model, like the TDM Evaluation model it is based on, requires extensive inputs from regional agencies in the form of baseline and improvement case trip tables for each type of TCM. Due to the intense data requirements of STEAM, it was not selected for this study.

Of the spreadsheet-based analysis tools and models, the 2005 updated version of the EPA Commuter model appeared to be most commonly used at the state level. A tool known as TRIMMS (Trip Reduction Impacts for Mobility Management Strategies) has recently been developed by the University of South Florida and is capable of modeling the synergistic effects between strategies. Other sketch planning tools include TCM Analyst, developed by the Texas Transportation Institute and the Transportation Emissions Guidebook (TEG), developed by the Center for Clean Air Policy (CCAP). These sketch planning tools can be used to analyze a large number of strategies across multiple regions. However, the TCM Analyst model is based on relatively old data, having been developed in 1994-95, and the CCAP TEG model is a less precise tool than either the EPA Commuter model or TRIMMS because it is based on rule of thumb guidance on TCM impacts obtained from literature and requires many more assumptions (see Table A-2 in the Appendix for a comparison of several relevant models). All of these tools, including the most recent version of TRIMMS, provide changes in travel activity along with the corresponding reductions in emissions that are built into the model.

Two of the models identified in the research, the US DOE - EPA MARKAL (Market Allocation)-MACRO model and the US DOE National Energy Modeling System (NEMS) model, only analyze strategies affecting user costs applicable at a national scale, such as changes in fuel taxation and distance-based pricing, but they cannot evaluate regional or urban strategies and were not created for that purpose. For example, NEMS, the more detailed of the two models, can only analyze strategies at the broad level of the nine Census regions, not at an urban or sub-region level.

Smaller regions may not have the data needed for more sophisticated tools. On the other hand, larger regions that have the required expertise and tools often rely on multiple staff to provide data for modeling a single strategy, which requires much time and resources. It was found that sketch planning tools are widely used to analyze TCMs in large and small regions because they provide greater versatility to analyze a variety of strategies using a common, standardized platform. Several potential tools were compared for their suitability in undertaking this analysis. Tables A-1 and A-2 in Appendix A show the various features of all models that were explored.

Based on conclusions drawn from the research, the TRIMMS 2.0 model was used for the analysis effort, an updated version of the original model developed in 2009 with funding from U.S. DOT and Florida DOT. The TRIMMS 2.0 model was selected for its ability to handle synergies and substitution effects among TCMs in a robust way, using values of cross-elasticity between modes to calculate changes in mode shares. This assumes that the different mode choices are not independent of each other, but rather are interactive. For example, when financial incentives like fare subsidies are provided for the use of transit and higher parking fees or tolls are introduced for autos, TRIMMS can capture the combined VMT effects of the resulting shift in mode shares. The model also allows the user to capture the effects of TCMs in different timeframes by the use of short term and long term elasticities, as well as to distinguish peak and off-peak impacts at the regional scale. Additional information related to the TRIMMS model is included in Appendix A.

2.5 Subject Matter Expertise

Recognizing that changes in travel patterns, characteristics, and modes may change the effectiveness of TCM strategies, a review of the national literature was used to identify experts in TCM implementation, research on land use interactions, and emissions analysis techniques. Subject matter experts selected from both the academic environment as well as knowledgeable transportation professionals bring practical experience to apply to the considered research and data. Five experts provided feedback on the methodology and the policy scenarios, provided recent studies on the impacts of TCMs and data they had come across in their work, and reviewed an interim report for the analysis. Their inputs were used to revise and enhance the methodology, highlight caveats, and validate the results of the analysis.

Chapter 3: Analysis Methodology

This chapter describes in detail the steps that were taken to conduct the analysis. These steps are the framework for the **T**ravel **E**fficiency **A**ssessment **M**ethod (**TEAM**). The effort began by dividing metropolitan regions into seven types or "clusters" and then selecting two representative metropolitan regions for each cluster. Concurrently, TCM strategies were selected for analysis and defined to meet the requirements of the TRIMMS model. Finally, individual strategies were combined into seven scenarios. The scenarios begin with a single strategy, the use of region-wide TDM, and add increasingly challenging strategies such that the final scenario represents the combined impact of all strategies.

The resulting framework of clusters and scenarios allowed data collection and input for modeling. A three-step analysis approach was used to determine: (1) potential VMT reduction in the representative regions through the TRIMMS analysis, (2) anticipated cluster-level reductions in both VMT and emissions by averaging the regional results, and (3) a national-level forecast of VMT and corresponding emissions reductions from 2010 to 2050 in 10-year increments. Emissions reductions were determined using factors from the MOVES2010 model applied both at the cluster and national level.

3.1 Representative Metropolitan Region Selection and Data Use

As described in Chapter 1, nationwide VMT and GHG emissions reductions under different TCM scenarios were estimated by extrapolating the modeling results based on real data from representative regions to regions with similar characteristics in the same cluster, and then summing the results across clusters.

To characterize the clusters, data were collected for all U.S. Census metropolitan statistical areas (MSAs) around the following variables: population; area; proportion of people who use transit, drive alone, or carpool to work; total daily VMT and road miles; and calculated population density, daily VMT per capita, and road miles per capita. Formal statistical methods and graphical estimation were used to identify the explanatory variables from the data, that is, the variables that control the other data. Population and transit mode share were found to be explanatory variables and were used to define the clusters. Using the population and transit mode share data collected for the MSAs, all metropolitan areas across the country were placed into the seven clusters. The identification of clusters as "high" or "low" transit use is based on the average value for the regions within that cluster. Table 2 illustrates the breakdown of U.S. metropolitan areas into their representative clusters.

The characteristics and representative metropolitan areas for each cluster are shown in Table 3. The four clusters with the largest populations were defined by both population and transit mode share. The three clusters with the smallest populations did not differ significantly in transit mode share so were defined only by population. The representative metropolitan areas in each cluster were chosen with consideration for geographic diversity, their approaches and strategies to address climate change and greenhouse gas emissions, the ability for the metropolitan area to represent areas with similar characteristics, data availability, and MPOs' interest in providing useful data. Although metropolitan areas in California were used to represent four clusters, this was considered advantageous because of the population density in California and the innovative approaches historically used in California that can benefit other regions. Many of the states in the center of the country are relatively low in population and are not currently designated as air quality non-attainment areas, affecting the availability of data.

Table 2. U.S. Metropolitan Regions in Clusters				
Cluster Definition	Total Daily VMT	Share of National Daily Urban VMT	Average Share of Transit	Number of U.S. Cities Represented
Cluster 1 [pop > 2.9 mil; transit share > 9%]	846,523,000	17%	15.6%	6
Cluster 2 [pop > 2.9 mil; transit share 9% or less]	1,084,936,000	22%	3.9%	9
Cluster 3 [pop 1.5 - 2.9 mil; transit share > 4%]	314,828,000	6%	6.4%	7
Cluster 4 [pop 1.5 - 2.9 mil; transit share 4% or less]	368,438,000	7%	2.5%	8
Cluster 5 [pop 750,000 - 1,499,999]	585,546,000	12%	3.5%	21
Cluster 6 [pop 250 - 749,999]	914,805,000	18%	1.8%	87
Cluster 7 [pop < 250,000]	832,103,000	17%	1.6%	313
SUM TOTAL	4,947,179,000	100%	2.0%	451

Table 3. Cluster Definitions and Representative Areas		
Cluster	Definition	Representative Areas
1	Population ≥2.9 million High Transit Share (>9%)	San Francisco, CA Washington, DC
2	Population ≥2.9 million Low Transit Share (9% or less)	San Diego, CA Seattle, WA
3	Population 1,500,000-2,899,999 High Transit Share (>4%)	Portland, OR Denver, CO
4	Population 1,500,000-2,899,999 Low Transit Share (4% or less)	Sacramento, CO Salt Lake City, UT
5	Population 750,000-1,499,999	Memphis, TN Raleigh-Durham, NC
6	Population 250,000-749,999	Fresno, CA Knoxville, TN Rochester, NY
7	Population < 250,000	Burlington, VT Wilmington, NC

Actual regional travel data inputs and related information in the analysis were used to support a national-level understanding of the results that is grounded in reality. However, specific regional data and response to strategies creates the possibility that unique characteristics of a region could bias the national results. In order to minimize this potential for bias, the study used data from two participating regions with similar size and transit use to develop a range of possible impacts. The average of the response of the representative regions to a scenario was considered representative of other regions with similar characteristics.

Using this approach in a sketch planning analysis, the collected regional data quickly loses their connection to the representative region and becomes a general characteristic for a segment of the national transportation demand. This is why the cluster-level results should not be considered representative of the response expected for any specific region. However, there is value in understanding response to strategies at a finer scale than the national perspective provides. Because the analysis was conducted in increasingly aggregate levels, some conclusions can be drawn at each level. The Results and Conclusions section of the report provides some of the insights gained at the regional and cluster level in addition to providing national results.

The primary criteria used to identify potential MPO participants were population and transit share. Secondary consideration was given to geographic diversity and current use of TCMs. Ultimately, fifteen MPOs agreed to provide specific data from their travel demand model, regional long range transportation plan, and individual special studies.

Because the individual MPO travel demand models varied considerably in complexity and detail, it was important that the data analyzed in this study be consistent across the regions. A data collection form (shown in Appendix B) that focused on model inputs and outputs was provided to all participating MPOs. While the requested data were not uniformly available, the regions were not asked to perform any additional analysis in order to generate the data for this study. However to supplement the collected information, interviews were conducted as necessary with identified modeling and planning staff for a full understanding of the information. As the analysis was conducted and compared with the information compiled from the literature review, urban planners from the individual regions were consulted when the outcomes appeared counter-intuitive or strongly outside the normal range. This partnership with the metropolitan areas provided as robust an understanding as possible for this level of analysis. The data collected from research on expected TCM impacts and range of elasticities were used to address gaps in data or to support detailed assumptions for the analysis.

Regional travel demand modeling specifies a base year and a horizon year for the current long range transportation plan. Although some areas had identified intermediate years in their planning analysis, these data were used only as supporting information. In general, the base year data were assumed to represent 2010 conditions and the horizon year data to represent 2030. This assumption provides the basis for many subsequent assumptions and allows the data to be forecast to 2050.

Additional validation of this approach and use of data was provided by expert review. Each expert provided detailed knowledge of the state of the practice with regard to individual strategies. These experts were engaged from the outset and helped shape the methodology through their knowledge of what could be anticipated and where significant meaning could be gained or missed. Their input was used to adjust the methodology within the limitation of the sketch planning analysis and the intended purpose to provide national-level results and understanding.

A significant treatment of the data used in the analysis was the combining of trip purposes for scenario evaluation with the exception of using only work trips in the TDM scenario. A concern shared by several of the experts was that mode splits and elasticities are very different for work and non-work travel. Using average mode split and elasticities across all trip purposes was considered more appropriate based on the desire to apply the results to all metropolitan areas represented by a cluster. Alternatively, by selecting a specific mode split or using multiple trip purposes, the results would become less broadly applicable. Although this averaging is considered appropriate for a national-level analysis, subsequent efforts to apply the methodology and/or results at a regional level should consider this issue and adjust appropriately.

3.2 Strategies Analyzed

There are many TCMs that can reduce VMT, but their degree of effectiveness varies. A comprehensive list of TCMs is provided in Table A-3 (see Appendix A). In selecting TCMs for analysis, consideration was given to: (1) measures under consideration by the widest range of MPOs in recent years as indicated by the survey response and (2) measures that offer the greatest potential to reduce automobile trips and VMT from the literature review. These individual measures were then grouped for analysis into four general strategy categories, to take advantage of natural synergies and to draw conclusions that are meaningful at the national scale.

The strategy categories for reducing vehicle travel demand selected for analysis are shown in Table 4. They include: (1) travel demand management incentives provided by employers, (2) land use strategies including transit-oriented development and promotion of higher densities, (3) changes in public transit travel times or fares, and (4) pricing of auto travel including parking charges. The analysis did not specifically address vehicle technologies and alternative fuels within the strategies. It is anticipated that changes will occur in these areas in the future, and this is represented in the emissions analysis using MOVES2010. In addition, the national-level baseline also includes assumptions related to fuel technologies, fuel economy, and fuel prices for light duty vehicles in addition to macroeconomic variables and is drawn from the U.S. Energy Information Administration's Annual Energy Outlook (AEO) 2009. For more information, see the national-level analysis section (3.3).

The description of strategies provided here is supplemented with more detailed information in Table 6, highlighting the assumptions used in the analysis of scenarios.

Table 4. TCM Strategies Analyzed

Strategy Categories	TCMs Included in the Analysis
Travel Demand Management (TDM)	Rideshare Programs
	Employer-based Programs
	Public Outreach/ Education
Land Use / Smart Growth	TOD: Improved Transit Access
	Mixed Land Use
	Promotion of Higher Density
Transit	Increased Transit Frequency
	Lower Fares or Transit Subsidies
Pricing	Parking Pricing
	Mileage Fees

- **Strategy 1: Region-wide Travel Demand Management (TDM)**

  TDM policies were evaluated using the percentage of employees or working population in the region that are assumed to be affected by flexible work hours, telecommuting, guaranteed ride home programs, modal subsidies, and incentives for carpooling, walking, and biking. As noted above, the TDM strategy applies only to work trips while all other strategies apply to total trips across all types.

The TRIMMS model considers TDM strategies to be supporting strategies or "soft programs." Because these are typically voluntary programs initiated by employers, they are included in packages of measures along with other strategies aimed at altering travel behavior. Thus the TRIMMS model assumes that voluntary travel behavior initiatives lead to changes in travel behavior only in the presence of other strategies related to transit, land use, and pricing, often referred to as "hard programs." Although these strategies do not have a direct impact on the cost of driving or the value of travel time in the model, they exert an indirect effect on the choice of alternative modes. TRIMMS models the impacts of region-wide TDM strategies on travel behavior using a set of previously estimated parameters based on an econometric analysis of the relationship between hard programs and soft programs like TDM (CUTR 2007).

- **Strategy 2: Land use strategies**

The analysis of land use strategies at the regional scale is subject to a number of uncertainties. Land use strategies are often modeled in terms of assumptions about one or more of five "D" variables -- density, diversity, design, destination accessibility, and distance to transit facilities as part of transit-oriented development. The individual effects of land use strategies such as transit-oriented development (TOD), promotion of higher density, or incentives for mixed use development, are difficult to estimate in TRIMMS or any tool that does not analyze impacts at or below the level of sub-areas such as traffic analysis zones. Although studies that attempt to do this are available, it is difficult to isolate the impacts of these strategies (or "D" variables) from each other since they are closely related. Therefore, these strategies are often combined together in scenarios representing smart growth, as for instance, in the *Moving Cooler* study. Similarly, in this research a single land use scenario was modeled that combined the effects of some common strategies including density increase, mixed use development, and TOD. In doing so, assumptions were made, consistent with the literature, for each mode with respect to changes in travel time and trip lengths resulting from the land use strategies considered. In this approach the land use scenario is based on expected changes in travel conditions from previous studies (Bartholomew and Ewing 2009; Ewing and Cervero 2010, Ewing et al. 2008a, Rodier 2008). Congestion effects arising from increased density were also considered for the automobile mode.

The literature review was also relied upon to inform the selection of parameters used in the TRIMMS analysis. To model the land use strategies, the TRIMMS model was used to calculate the change in VMT using elasticity values for travel time. These values for expected changes in travel time (access time and in-vehicle time) and trip lengths resulting from land use measures were based on a review of the above mentioned studies and values included in EPA's Smart Growth Index (SGI) model. This method allowed the modeling of scenarios that combine land use with other strategies in TRIMMS in order to allow comparison with other strategies. The most accurate method of modeling land use impacts is with a disaggregated model that can capture land uses at a zonal or sub-area level.

- **Strategy 3: Transit Fare Changes and Service Improvements**

In this analysis, transit service improvements refer to an improvement in transit travel time through improved service frequency. Because the analysis used improvement in transit access and/or travel time as inputs, the results represent the VMT reduction possible from any of several strategies to improve transit service and operations. TRIMMS was used to analyze strategies in this category with the application of documented transit travel time elasticity values (Litman, 2010). Another transit-related strategy modeled is fare reduction, reflecting employer subsidies for transit use or commuter discounts offered by transit agencies. For instance, the Denver MPO has considered highly subsidized or free transit in a scenario that includes congestion pricing for automobiles.

To analyze the impacts of transit fare discounts and subsidies, price elasticities of transit travel demand were used in the TRIMMS model. The elasticities reflect the sensitivity of transit mode share to a change in the cost of commuting by transit, and as mentioned above, were obtained from a survey of the literature (Concas and Winters 2009). Note that the impacts of improving qualitative aspects such as the quality of transit service cannot be captured in this analysis. The category of transit-related strategies modeled the effects of: (1) higher transit frequency and (2) lower transit fares through discounts, subsidies, free transfers or other policies.

- **Strategy 4: Pricing policies with Mileage Fees and Parking Charges**

  In this category, the VMT impacts of pricing strategies that affect the operating costs of vehicles including higher parking charges, mileage fees and/or congestion charges were modeled using TRIMMS. However, corridor-level tolls and cordon-based or area-wide pricing policies cannot be modeled since these require detailed disaggregated information for sub-areas, such as mode shares and travel costs on particular corridors or groups of TAZs in a region. This information can be effectively analyzed only by the regional travel demand models.

  Since complete information to model congestion charges was not available from all regions, only mileage fees were modeled in this category. In TRIMMS, congestion charges can be modeled by applying the increased cost to a specific proportion of all trips (e.g., peak hour trips only). Ongoing studies show that regions considering mileage fees favor a congestion pricing component that allows the fee to vary by location and time of day in future years. The analysis takes this into account and applies the higher mileage fees in the peak hours, using data on the proportion of trips occurring in peak hours provided by each MPO. The mileage fees are applied to a baseline level of auto operating costs provided by each MPO. Although parking charges are best modeled at a disaggregate scale using zonal information, it is possible to do a sketch-level analysis at a regional scale. In this analysis, parking charges were considered as a separate auto pricing strategy, using information received from the regions on existing average daily parking charges and policies under consideration for increasing parking prices at a region-wide scale.

3.3 Scenario Development

In order to develop individual scenarios for analysis, the strategies were combined to form the seven scenarios shown in Table 5. The combinations were based on natural synergies, building cumulatively from the most basic strategies to the most aggressive. This approach and the resulting combinations are representative of the general order in which regions typically consider implementing TCMs.

Table 5. Scenarios						
Scenario	Strategy Combinations					
	Region-wide TDM	Land Use/Smart Growth	Transit Fare Reduction	Transit Service Improvements	Pricing Mileage Fees	Pricing Parking Fees
Baseline	Current conditions without any of the above strategies					
Scenario 1	✓					
Scenario 2	✓	✓				
Scenario 3	✓	✓	✓			
Scenario 4	✓	✓	✓	✓		
Scenario 5	✓	✓	✓	✓		✓
Scenario 6	✓	✓	✓	✓	✓	
Scenario 7	✓	✓	✓	✓	✓	✓

One purpose of the study is to analyze prospective TCMs that are not widely used today, and where few estimates of the benefits currently exist. Some of these measures such as mileage fees, smart growth, and parking pricing are relatively new. They have been receiving significant attention in recent years and are of substantial interest to state and local policy makers. Wherever possible, the results of the analysis of these strategies were validated using existing studies.

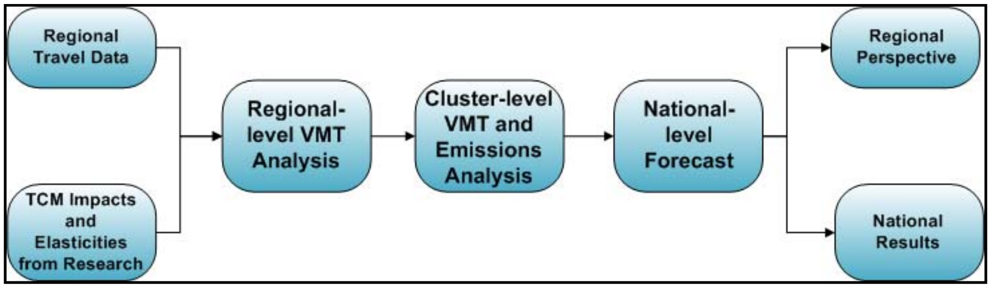
The use of scenarios combined with the modeling approach, is unique with respect to other national-level studies that attempt to quantify potential future reductions in emissions resulting from these strategies. Recent studies have used individually established baselines along with current research findings to develop meta-analyses which evaluate strategies independent of one another. In contrast, this research approach relies on available data from metropolitan regions that act as representatives of similar regions. The scenarios take into account natural synergies between strategies to demonstrate the effect that can be built over time as strategies are incrementally added.

3.4 Scenario Analysis

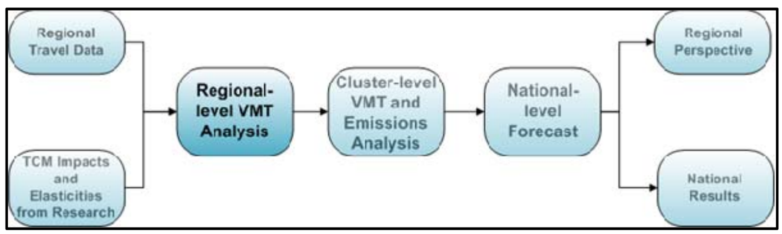
The foundation of the analysis is detailed travel data submitted by participating metropolitan regions. These data provide specific inputs to the TRIMMS modeling and support an understanding of how individual TCMs are currently included in regional transportation planning. The analysis was further informed and supplemented by consideration of recent research on TCM impacts and elasticities.

Each step in the analysis moves progressively toward estimating the national potential for reductions in VMT and corresponding emissions reductions. The first step was to model the application of scenarios in order to estimate VMT reductions for each of the representative areas. In the second step, results of the representative area analysis were used to develop the potential VMT and emissions reductions for each of the seven clusters. Finally, the cluster results were applied to all metropolitan regions in the country based on their defining characteristics and aggregated to provide a national-level forecast of VMT and emission reductions. This methodology was followed to analyze each scenario, or group of strategies, and is described in detail below. The appendices contain the specific data inputs and assumptions as well as results at the cluster and national level. Figure 1 below illustrates the sequence of analysis steps followed.

Figure 1. Analysis Steps



Step 1: Regional VMT Analysis



Analysis at the regional level provides the necessary connection to real-world metropolitan transportation systems through the use of existing and forecasted data from the participating representative areas. Estimating the regional VMT effects of individual strategies and scenarios is the first step in the analysis.

The individual features of the scenarios modeled were based on programs and policies that have either already been included in MPO plans or are currently being considered in different regions. Baseline data on the number of trips, trip lengths, trip times, vehicle occupancies, and trip costs for each mode were obtained from metropolitan regions representative of all seven clusters. For each scenario, the strategy assumptions or parameters have been drawn from a thorough literature review of strategies proposed regionally and nationally, information received from MPO surveys about their modeling assumptions, and professional and academic studies focusing on scenario analysis of TCMs. These references are listed at the end of the report. The assumed features of each strategy are in Table 6.

Table 6. Scenario Assumptions and Modeling Approach for TCM Strategies

TCM Strategy	Specific strategy	Strategy information	2010 - 2030	2030 - 2050
Employer-based TDM strategies	▪ Flexible work hours ▪ Incentives for carpooling ▪ Guaranteed ride home programs ▪ Ride sharing/ ride matching ▪ TDM outreach/public outreach programs ▪ Subsidies/discounts for transit, pedestrian and bike modes ▪ Telecommuting	Whether or not employer offers (TRIMMS asks for a yes/no answer) to take these programs into consideration	30% of employers Region-wide offer these programs; includes all TDM strategies except walk and bike subsidies	50% of employers Region-wide offer these programs; includes all TDM strategies

Table 6. Scenario Assumptions and Modeling Approach for TCM Strategies

TCM Strategy	Specific strategy	Strategy information	2010 - 2030	2030 - 2050
Land use policies	TOD, smart growth, increase in density, mixed use developments	Change in travel times for all modes, change in average trip lengths	3% reduction in all access times, 5% reduction in transit travel time and walk/bike times; 5% increase in auto travel time due to density/ congestion effects	6% reduction in all access times, 10% reduction in transit travel time and walk/bike times; 10% increase in auto travel time due to density/ congestion effects
			Note: Access time taken as proxy for trip length.	
Transit projects and policies	Transit service expansion/increase in frequency, improved access	Improvement in transit travel time and access time	5% reduction in transit travel time	10% reduction in transit travel time
	Fare discounts, reduction, subsidies, or free transfers	Change in transit fares	10% reduction in transit fares	20% reduction in transit fares
Pricing policies	Parking charges	Increase in auto parking costs	$2 increase per day	$5 increase per day
	VMT fees or congestion pricing	Increase in peak hour driving costs	$0.10 increase per mile	$0.25 increase per mile

Using the base year and horizon year plan data available from each of the MPOs, each scenario was modeled in two timeframes – (1) in 2010 with impacts expected to occur by 2030, and (2) in 2030 with impacts expected to occur by 2050, although the effects of these scenarios will occur over different time frames. This was because the input data consistently available from all MPOs was for their base year (2005-2010 timeframe) or future year (2030-2040 timeframe). The intent has been to simulate the gradual application of strategies in every decade while accommodating a natural growth in regional VMT by applying two implementation phases for each scenario. With population and economic growth, VMT is expected to grow in future years and the effectiveness or adoption of strategies would also most likely increase over time. Both these factors were taken into account in projecting the VMT reduction for each scenario. The growth rate assumed for the growth in baseline national VMT was 1.47%, the average growth rate per annum in 2030 assumed in the Annual Energy Outlook 2009 (U.S. Energy Information Administration 2009).

The reduction in VMT for a given year was measured from the baseline VMT for that year in the absence of any strategy. This was estimated by the TRIMMS model using the population, trip length, and mode share data provided by the regions as well as regional trip rates. In designing the scenarios, the assumptions for the base and future years were varied to simulate the increase in the expected rate of adoption or effectiveness of a strategy over time. Future year scenarios were, therefore made more aggressive than base year scenarios. Also, larger values of travel time and travel cost elasticities were used to estimate impacts in future years. This reflects the greater long-term impact of strategies owing to greater adoption and effectiveness over time. A primary assumption in the analysis is that the strategies would take effect over approximately a 20-year period. This assumption is based on the inclusion of land use strategies in all scenarios. Land use changes take effect over the longest period of time, either passively or through active policy intervention.

As laid out in the scenarios, strategies were combined and modeled together and the VMT reduction reflects the cumulative reduction for all strategies from the business-as-usual baseline out to 2050. The long-term outlook was incorporated in the analysis in two ways: (1) As shown in Table 6, a more aggressive scenario was assumed in the future year, and (2) the travel time and cost elasticity values were increased in the future year analysis, based on a survey of long-term and short-term elasticities (Concas and Winters 2009). For example, if 15% of employers are assumed to initiate TDM measures in the base year, this figure may be increased to 30% in the future year analysis. Transit subsidies in future years may also be expected to increase. To incorporate the need to consider the differing relevance and effectiveness with which strategies are applied in different regions, one of the strategies, application of VMT-fees, was not considered in cities with population lower than 1.5 million. VMT-fees, also known as mileage fees or distance-based pricing, is considered a fairly aggressive strategy in the regions surveyed and has not been implemented for light duty vehicles, except in the form of small-scale pilot programs in large metropolitan areas like Seattle and Portland. Congestion needs to be at a significantly high enough level for a region to consider this strategy, so it may not be warranted for small and medium metropolitan areas.

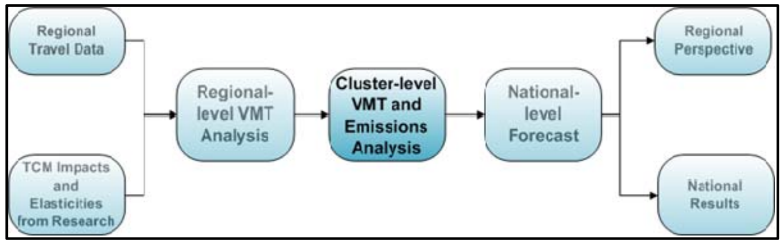
The current year data provided by the regions are indicative of the present situation, while the future year data indicate how the region expects to grow over the next 20 years. Although the attempt was made to model the future year with none of the policies implemented, some regions provided future year data that accounted for infrastructure investments in transit or other facilities and land development. This occurred in regions that have already been implementing actions towards more sustainable transportation, and specific infrastructure changes cannot be separately accounted for in a sketch level analysis. For instance, Portland was one of the few regions where trip lengths are expected to decrease in the future and the resulting effect is seen in the VMT analysis.

The 2030 baseline data provide the best estimate of a future year base case available. Baseline data for intermediate years were not largely available. Therefore, to simulate the effect of applying a strategy progressively in each decade, the effect of applying the strategy at two levels was calculated. First, a milder version of the strategy was applied in the current year with complete effects occurring over the following 15-20 years. Second, a more aggressive version of the strategy was applied in the future year (2030) with complete effects expected to occur by 2050.

Once impacts were calculated to 2030 and 2050, straight line averages were used to provide the expected VMT reduction in intermediate years. Elasticity values considered for the future year were assumed to be long-term elasticities found in the literature that are higher than the short-term elasticities used for the current year analysis. This captures the effect of increased adoption or compliance rates in future years, once a policy has been in effect for some decades.

In addition to the assumption about when impacts can be expected to occur, the application of strategies across all trip purposes may not be representative of individual regions. Mode splits and elasticities are very different for work and non-work travel, and individual regions have identified specific trip purposes as a basis for their travel demand modeling. While comparison of strategy effects across trip purposes will be meaningful for individual regions, using one trip purpose is more appropriate in this analysis because the impacts at the regional level are ultimately aggregated to the national level. As stated previously, the exception is for TDM strategies, which are applied to work trips only and are combined with other strategies in every scenario.

Step 2: Cluster-level Analysis



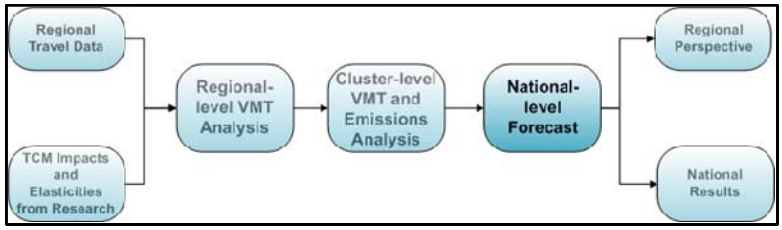
The second step of analysis moves beyond the analysis of individual regions to estimating the response of any region with similar population and transit use. In this step the regional response in VMT of two representative areas is averaged for each scenario. The resulting data are then used to calculate the associated emissions. This provides the VMT and corresponding emissions that may be reduced by travel behavior changes in each representative cluster.

The Motor Vehicle Emissions Simulator (MOVES2010) emission model was designed as the replacement for EPA's previous mobile source emission factor model, MOBILE 6.2. MOVES2010 represents the most advanced state-of-the-practice in estimating on-road mobile source emissions. At its core MOVES2010 is a database based on analysis of millions of emission test results and considerable advances in the understanding of vehicle emissions. It incorporates several changes to the EPA's approach to mobile source emission modeling based upon recommendations made by the National Research Council (NRC 2000) Given the improvements in the current MOVES model over its predecessor for several of the pollutants of interest, MOVES (EPA http://www.epa.gov/otaq/models/moves/index.htm) is the best model to use in this analysis. At the time this report was being written, EPA was anticipating the release of the next version of the model, MOVES2010.

On-road driving emission factors for urban roads as well as off-network emissions, including start and refueling emissions, were derived with MOVES2010 employing national default fleet characteristics. The study focus is on light-duty vehicles and as such only considered gas and diesel fueled passenger cars and trucks. The emissions analysis was conducted for each representative cluster. All factors were derived from an emission inventory approach, normalizing total emissions to total activity rather than directly exporting emission factors from the model. Starts were linked to trips assuming one start for each vehicle trip.

Emissions factors were determined for criteria pollutants (NO_x, PM, and VOC), and the three principal GHG pollutants (CO_2, CH_4, N_2O). All exhaust species consider tailpipe and crankcase emissions. Particulate matter (PM) species also include brake and tire wear. Volatile Organic Compounds (VOC) emissions include exhaust and refueling emissions, although evaporative emissions were not included. Emissions were determined for the current year (2010) and a future year (2030) for each representative cluster. Total national emissions reductions were subsequently determined by multiplying the representative cluster results by the number of metropolitan areas the cluster represents.

Step 3: VMT and Emissions Impacts at the National Level



From a national perspective, the response of each cluster to the analysis represents the anticipated response of all regions which match the associated characteristics. For example, Cluster 1 represents all metropolitan areas that have a population above 2.9 million and a transit share greater than 9%. Based on the U.S Census definition of urbanized areas in 2007 there are six metropolitan areas that meet this description. Therefore the results of the Cluster 1 analysis are applied to six metropolitan areas in the nation, with the expectation that they are likely to respond similarly. Combining the results of the six areas provides the total potential contribution of Cluster 1 areas to the national reduction in VMT and corresponding emissions. The resulting VMT and emissions reductions for each cluster are then combined to estimate the national response to each scenario in 2010 and forecasted for each subsequent decade up to 2050. The specific methodology is described below and in Table 7.

The baseline used for light duty VMT for the years 2010-2030 in this study is from the U.S. Energy Information Administration's Annual Energy Outlook (AEO) 2009. The AEO projections were available to 2030 and were extrapolated to 2050. The AEO uses assumptions related to fuel technologies, fuel economy, and fuel prices for light duty vehicles to estimate the VMT in future years, in addition to macroeconomic variables like gross domestic product, disposable personal income, industrial output, new car and light truck sales, and population. These assumptions are based on current policies such as state and federal government mandates for minimum sales volumes of alternative-fueled vehicles (see U.S. Energy Information Administration's AEO 2009 for a complete set of assumptions).

Table 7. Methodology for Scaling to the National Level

Data Available for Analysis*	Methodology Applied
A. VMT reduction – number of miles by scenario by cluster and by decade B. Emission reductions – pollutant by scenario by cluster and by decade (includes start, refueling, and urban driving emissions) C. Number of regions nationwide that belong in each cluster (based on FHWA 2007 urbanized area populations and 2000 Census Transportation Planning Package transit shares) D. Share of national VMT attributed from each cluster (FHWA 2007 VMT data) E. EPA Forecasted National VMT (2005 – 2030; extrapolated for 2040 and 2050): 68% of the national VMT are assumed to be urban, based on several data sources * Note: letters indicate variables used on right side	1. National Cluster VMT Reduction = Clusters(i) (Ai x Ci) per scenario and decade 2. National Cluster Emissions Reduction = Clusters(i) (Bi x Ci) per scenario, decade and pollutant 3. National VMT Reduction = Sum of Clusters(i) 1-7 (Ai x Ci) per scenario and decade 4. National Emissions Reduction = Sum of Clusters(i) 1-7 (Bi x Ci) per scenario, decade and pollutant 5. Percent National VMT Reduction = (E - National VMT Reduction) / E 6. Percent Cluster VMT Reduction = Sum of all cities with Cluster(i) (E*D - National Cluster VMT Reduction) / E*D per scenario and decade

In order to scale up the regional VMT reductions to the national level, the VMT shares for each metropolitan cluster were determined using the FHWA Highway Statistics Database for 2008 (FHWA 2009), which provides daily VMT for each urbanized area (population >50,000) in the United States. Using this database, the number of urbanized areas that fall within each of the clusters was also determined. Using the national VMT projections from the AEO and a factor of 68% derived from the same database to estimate the proportion of the national VMT that is urban, the contribution of each cluster to reducing overall national VMT was estimated. The results therefore represent the reduction in urban VMT and emissions nationwide because the TCM scenarios are primarily applicable in urban areas and the data modeled were for urban areas. The scenarios considered in this analysis are not expected to affect VMT in rural areas.

The same procedure was followed for the emissions reduction estimates derived for each cluster and for the nation as a whole. However, unlike VMT, a national baseline for emissions was not available. Future projections for both trips and VMT are required to create such a baseline because the number of trips helps determine the magnitude of emissions associated with vehicle starts. Therefore, to estimate the reductions in national emissions, a baseline was derived using regional data for trips scaled up to the national level, as described above, and the AEO 2009 VMT. It is important to recognize that over time some rural areas will convert to urban areas. One study reports that while about two-thirds of national VMT is urban today, by the year 2050, about four-fifths of all national VMT will be urban (Ewing et al. 2008b). This change in relative proportions of rural to urban VMT was not considered in the analysis, as only one data source was available to validate this premise. The cumulative reductions in VMT and emissions from the business-as-usual baseline for all decades out to 2050 are presented in the next chapter. This baseline reflects the growth in VMT in the absence of any strategy being applied. The results can be found in Section 4.1 (Table 8) and in the appendices. This baseline reflects the growth in VMT in the absence of any strategy being applied. Specific results can be found in the appendices.

3.5 Data Limitations and Assumptions

The methodology and assumptions made in this report may lead to results that are more conservative when compared to other national studies. In order to support the regional analysis using TRIMMS, a number of decisions were required to account for incomplete or unavailable data. The decisions were guided primarily by current research and best practice observed in the metropolitan regions surveyed. Collectively these assumptions may result in an overall conservative result. However, this informs the full range of potential outcomes when considered within the context of other recent national studies. The following information describes the impact of the assumptions in the study and should be considered carefully when performing analysis of individual regions in order to more closely reflect their specific travel related characteristics.

1. *Regional trip cost data by mode:* Data on trip costs, particularly for non-transit modes are not easily available from all regions. Where automobile operating costs were not provided, trip cost was calculated based on average trip lengths that were provided, fuel price and other cost components, and mileage data for the base year. Regions particularly face a problem in modeling parking charges; aggregate regional analysis severely underestimates parking charges, therefore parking charges are best modeled at a sub-regional or zonal level. To resolve this issue, the analysis considered the highest parking charge available for the region as the baseline, under the assumption that strategies to reduce driving by increasing parking charges are most commonly implemented in locations where they are already high due to high land costs, congestion, and traffic volumes (e.g. in downtown areas). For transit trip costs, information was obtained directly from the regions or collected from the websites of the transit authorities.

There is no consistent methodology across regions to estimate future year trip costs; therefore, for the future year analysis, auto operating costs were kept constant. Most regions follow the practice of assuming constant auto operating costs in future years because of the uncertainty in how vehicle fuel efficiency and fuel prices would change in the future. This was the approach followed in the analysis. This assumption was considered acceptable because even though fuel prices may be expected to increase, higher vehicle fuel efficiency would be likely to help offset any increase in operating costs. Future year transit fares were assumed to rise with inflation at three percent per year, while future year parking costs were assumed to increase by two percent per year, following guidance used by some MPOs.

2. *Regional elasticity values by mode:* As expected, data in this category were difficult to obtain. Elasticity values were obtained from only two of the fifteen metropolitan areas that provided data. These elasticity values were compared with national values that were obtained from the literature review and found to be broadly within the same range. Some values in TRIMMS 2.0 are lower (more conservative) than the values obtained from the literature review, but the model allows users to specify their own elasticity values. Given that the majority of metropolitan areas were not able to provide regional elasticities, the same ranges of values for all metropolitan areas, derived from the literature review, were used. This is acceptable since it reflects the current state of the practice and information that is available from the literature. Despite similar elasticity values, the expectation was that there would be sufficient variation in strategy impacts between regions based on the differences in transportation data such as mode shares, trip lengths, trip costs, and travel times by mode.

3. *Uncertainty in future year trip length:* MPO estimates for future year trip lengths are highly uncertain since they depend on the implementation of several land development, transportation, and other planning strategies whose impacts are uncertain over the long term. Where available, the analysis used trip length trends (typically in the range of ± 2% compared to the base year) that were provided by the region through their future year planning efforts. For regions that did not provide this information, this analysis used the same trip lengths for the future year as in the base year. The assumption used here is that if regions had provided a trip length estimate for the future year from their models, they are likely planning for policies (land use and other strategies) or expected growth that will affect trip lengths. If regions were unable to provide horizon year trip lengths, it is likely that they do not expect trip lengths to change or are not considering measures that will alter trip lengths. Assuming the same trip length as in the baseline year implies a conservative estimate for this analysis.

4. *Impact of vehicle speed on emissions:* Although both speed and VMT are used in emissions analysis, speed represents a response to congestion rather than a change in travel behavior as indicated by a reduction in VMT. It is true that congestion can have an impact on emissions; however, these impacts tend to be smaller and more localized than the impacts of VMT reduction. In addition, the consideration of speed requires data at a greater level of detail and is best accomplished using the regional travel demand model. Because congestion impacts are very context-specific, the data required to analyze them are significant, and the selected tool for this study is not adequate for this analysis; the impact of reducing change in vehicle speeds on national emissions cannot be meaningfully considered within this study.

5. *Pricing strategies:* For the application of mileage fees, the use of average trip length as an input in TRIMMS provides an estimate of aggregate average impacts. Such a policy can be expected to offer the greatest VMT reduction for longer trips and trips made during peak hours, while potentially moving some auto drive-alone trips to off-peak hours and other modes. This shift may cause some of the reduction in auto drive-alone VMT to be offset by

6. *Using regional averages as inputs:* The impacts of some of the strategies such as TDM strategies and land use strategies will vary by trip purpose. For example, land use strategies are likely to have a higher impact on non-work travel than work travel and vice versa for TDM strategies. However, our input data were obtained as regional averages for mode shares, trip lengths, and trip costs, across trip purposes. Since the results are ultimately aggregated up to the national level, using average data inputs for a region are not expected to significantly affect the analysis, but it may slightly underestimate the impacts of these strategies.

7. *Limited application of pricing policies:* VMT-fees or mileage fees were not modeled for cities in Cluster 5, 6 and 7 primarily because the MPOs were unable to provide estimates of current vehicle operating costs which were required to calculate impacts. Although the data were not available, this was considered an acceptable limitation because currently no small cities are exploring VMT fees as a potential strategy. Clusters 5, 6, and 7 represent a large share of the national population, and therefore broader acceptance of pricing strategies may greatly affect the national perspective.

8. *National-level baseline:* At the national level, the light duty vehicle VMT baseline for the years 2010-2050 was available from the Annual Energy Outlook (AEO) 2009. However, no similar baseline was available for national trips, which was required to estimate emissions associated with vehicle starts. To estimate the reduction in national emissions, an emissions baseline was derived using regional data for trips scaled up to the national level reflecting trip start emissions and the AEO 2009 VMT reflecting driving emissions.

Chapter 4: Results and Conclusions

The purpose of this analysis is to provide a source of information on TCM strategy effectiveness to inform the discussion among federal, state, and local planning agencies interested in reducing mobile source GHG emissions. U.S. EPA and U.S.DOT as well as many state and local agencies support policies and programs in this effort. Estimates of the national potential for reducing VMT and GHG emissions may assist planning agencies in this regard. Although many of the results may appear intuitive and therefore less dramatic, the methodology and analysis provides quantifiable results rather than anecdotal evidence. It also allows comparison with other studies to inform the national conversation as well as the growing body of research.

While scenario modeling is based on actual travel data and characteristics of real metropolitan areas, the predicted changes to travel activity and resulting emissions are not intended to represent the effectiveness of the strategies for any particular area. The intent is to illustrate the potential effectiveness of strategies relative to one another, in combination, and with respect to travel behavior characteristics. However, the analysis provides additional information which may assist metropolitan regions in their efforts to address transportation-related emissions. By comparing their regional travel characteristics to the data used in the analysis, planner and policy makers may support regional discussions on the potential effectiveness of individual or groups of strategies. Through the allocation of staff resources and using local data and information in a detailed analysis, the region may more accurately estimate potential strategy effectiveness. This will help focus on those strategies that can be supported by policy makers and which appear to be the most promising for an individual region.

4.1 National Level Results

In general, greater opportunity for change results in a greater impact of strategies. Those regions with long trip length, high population growth, and limited strategies currently in place will show the most significant response to the scenarios. This response highlights the potential reductions that can be achieved from behavioral changes in the small and medium-sized regions that are experiencing high growth. In contrast, those regions that have initiated TCMs in a substantive way may need to consider more aggressive strategies. While a challenge for policy makers in the absence of public support, these areas could more effectively reduce emissions through incorporation of pricing strategies.

It would be a mistake to judge the response of TDM and land use strategies as demonstrating limited effectiveness as compared to the other strategies examined here. The TDM strategy was applied only to working population and work trips, and only a fraction of the total working population was assumed to be covered by employer-initiated TDM programs, therefore its impacts appear lower when compared to the other strategies. Within this research the assumption of 30% of employers participating in TDM programs in the current year and 50% in the future year may represent a conservative assessment based on recent gas prices and other external factors. As indicated previously, the importance of land use in supporting behavioral changes cannot be over-stated. In this study land use policy provides the basis for all strategies except TDM and is assumed to represent a slowly evolving change. We know that certain land use changes may be reasonably quick to implement in localized areas; however, studies show that the regional effect of localized change may appear relatively small initially and greater over the long term. This land use impact points to the importance of implementation in the near term in order to gain full effectiveness over the longer timeframe considered in this study. This paradigm is the basis for several assumptions in the analysis, and it impacts the level of total reduction identified in the period of study. Because TDM addresses behavior changes in work trips, and land use can be expected to have a stronger impact on non-work travel, using the two strategies in combination makes the most sense and can be implemented in any region as a starting point for more aggressive strategies.

The transit strategies provide an interesting comparison between fare changes and service changes. The analysis demonstrates a responsiveness to fare changes much greater than to service improvements. This implies that a policy decision on fare adjustments can be implemented quickly for an immediate response. Although reductions in fare have an impact on available funding, this should be much less than the cost of additional routes with higher operating and capital costs. Regions can be encouraged to target transit service to the greatest area of need rather than extend their reach to take in a larger area.

It seems very likely that as strategies are added, the actual results will be greater than the sum of the parts, capturing expected synergies between the strategies. For example, as the pricing element kicks in, it is very likely to increase the effects of land use strategies as people make residential and work location decisions to reduce their exposure to the effect of the pricing policies. The increasing range of response illustrated in Figure 2 supports this perspective. As the number of strategies applied increases, the percent reduction grows significantly.

There will be changes in socio-demographic factors between the present and 2050, such as the impact of an aging population on VMT, which cannot be accounted for in this analysis. The growing interest in “livable communities” is increasingly supported with grants and programs that may cause a dramatic long term effect if the policy is sustained. These more qualitative assessments can be used to adjust the input data in order to reflect expectations about future scenarios at both the regional and national scale. The range of VMT reductions across all clusters out to 2050 is broad because each city’s growth projection is so varied. The national reductions in Figure 2 reflect the percentage contribution of each cluster to national urban VMT. For graphical descriptions of all scenarios and clusters refer to the charts and tables in Appendix A.

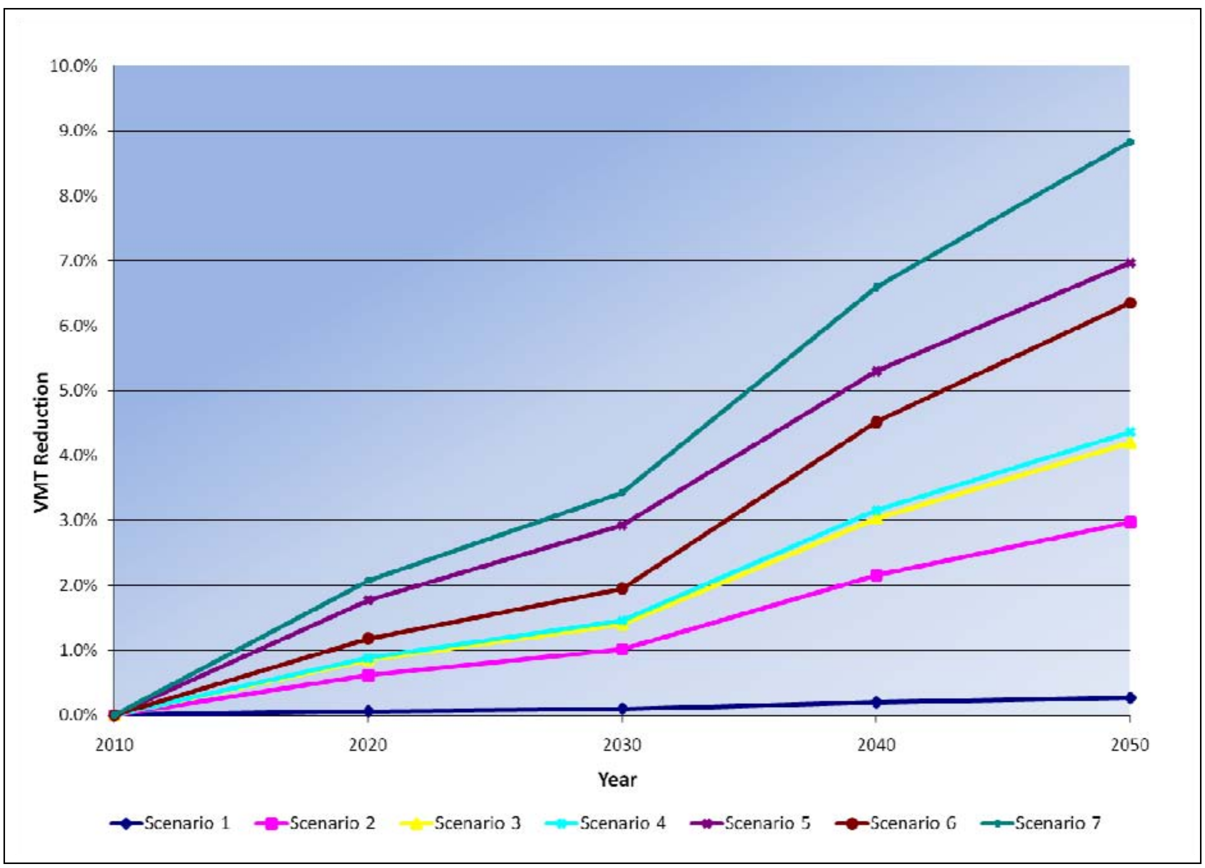
Table 8 shows the national reduction in urban VMT and emissions for light-duty vehicles estimated for 2030 and 2050 from the business-as-usual baseline. The reduction in 2050 represents the cumulative reduction expected over the four decades. As more strategies are added to the scenarios, the reduction in VMT increases. Emissions reduction percentages closely follow the VMT reduction across all pollutants. The impact of strategies on individual pollutants can be found in Table A-9 in Appendix A.

Figure 2 illustrates scenario response over time. The significant increase in effectiveness between Scenario 4 and 5 is notable. The addition of parking charges in Scenario 5 results in a dramatic reduction in VMT even though parking charges varied greatly across regions: from $2 to $11 per day in the base year. As previously mentioned, Scenario 6 was not applied to Clusters 5, 6, and 7 based on the lack of input data from representative regions and the lower relevance of mileage fees in these smaller regions. Consequently, Scenario 5 is the same as Scenario 7 for these regions. However, the addition of pricing strategies shows a strong increase even with fewer urban areas included. This may point to the synergistic effect of strategy combinations mentioned previously.

Table 8. National Percent Reductions				
	Percent VMT Reduction		Percent Emissions Reduction*	
Scenario	2030	2050	2030	2050
1- Regionwide TDM	0.1%	0.3%	0.1%	0.2-0.3%
2 - TDM + land use changes	1.0%	3.0%	1.0%	2.9 – 3.0%
3 - TDM + land use changes + transit fare subsidies	1.4%	4.2%	1.4%	4.1 – 4.2%
4 - TDM + land use changes + transit fare subsidies + transit service improvements	1.5%	4.4%	1.4%	4.2 – 4.3%
5 - TDM + land use changes + transit fare subsidies + transit service improvements + parking fees	2.9%	7.0%	2.9%	6.7 – 7.0%
6 - TDM + land use changes + transit fare subsidies + transit service improvements + mileage fees	2.0%	6.3%	1.9%	6.0 – 6.3%
7 - TDM + land use changes + transit fare subsidies + transit service improvements + parking & mileage fees	3.4%	8.8%	3.3 – 3.4%	8.3 – 8.8%

* Ranges reflect reductions in all pollutants considered. For example, Scenario 7 results in 8.3% reduction in volatile organic compounds (VOC), 8.6% reduction in NO_x, and 8.8% reduction in each of $PM_{2.5}$ and greenhouse gases (CO_2 equivalent).

Figure 2. National VMT Reductions from Baseline



Effectiveness of Alternative Aggressive Pricing Strategies

Because pricing scenarios result in the largest emissions and VMT reductions, additional analyses were conducted for pricing scenarios that exceed those being considered by the transportation planning agencies interviewed for this study. These more aggressive pricing strategies may be of interest to policy makers and planners. These scenarios were applied only to the larger cities in the first four clusters and only in the 2030 to 2050 timeframe. For parking charges, an average daily increase of $8 was used instead of $5, and for mileage fees, a peak hour fee of $0.35 was used instead of $0.25. The results of three new scenarios, which relate to Scenarios 5, 6, and 7 in Table 8, are provided below.

National Percent Reductions with Aggressive Alternatives for Pricing Strategies

Scenario	Pricing strategy included in scenario	Strategy Description	Level of charge	Percent VMT Reduction in 2050	Percent Emissions Reduction in 2050*
5A	Parking charges	Increase in daily auto parking charges	$8 per day increase	7.2%	6.8 – 7.2%
6A	VMT/mileage fees	Increase in peak hour driving costs	$0.35 increase/mile	6.7%	6.2 – 6.6%
7A	Parking charges and VMT fees	Increase in average auto parking and peak hour driving costs	$8 increase *and* $0.35 increase/mile	9.2%	8.6 – 9.2%

* Ranges reflect reductions in all pollutants considered.

Compared with the original pricing scenarios shown in Table 8, the alternative pricing levels shown above increase emission reductions only by a small amount nationally. The primary reason is that the effect of higher charges (applied only to the first four clusters) is diminished when averaged across all clusters. Clusters 5 though 7 retain the same charge levels in the 2030-2050 timeframe as in the earlier analysis. This reduces the full impact of the aggressive strategies when all clusters are combined for the national impact. In addition, once lower value trips are reduced in the earlier scenarios, these incrementally higher charges tend to shift the remaining higher value trips to off-peak periods and to other modes like rideshare rather than reduce them. While a shift to off-peak trips helps to reduce congestion, it does not reduce VMT. Similarly, a shift to rideshare reduces only some of the auto VMT.

4.2 Scenario Comparisons

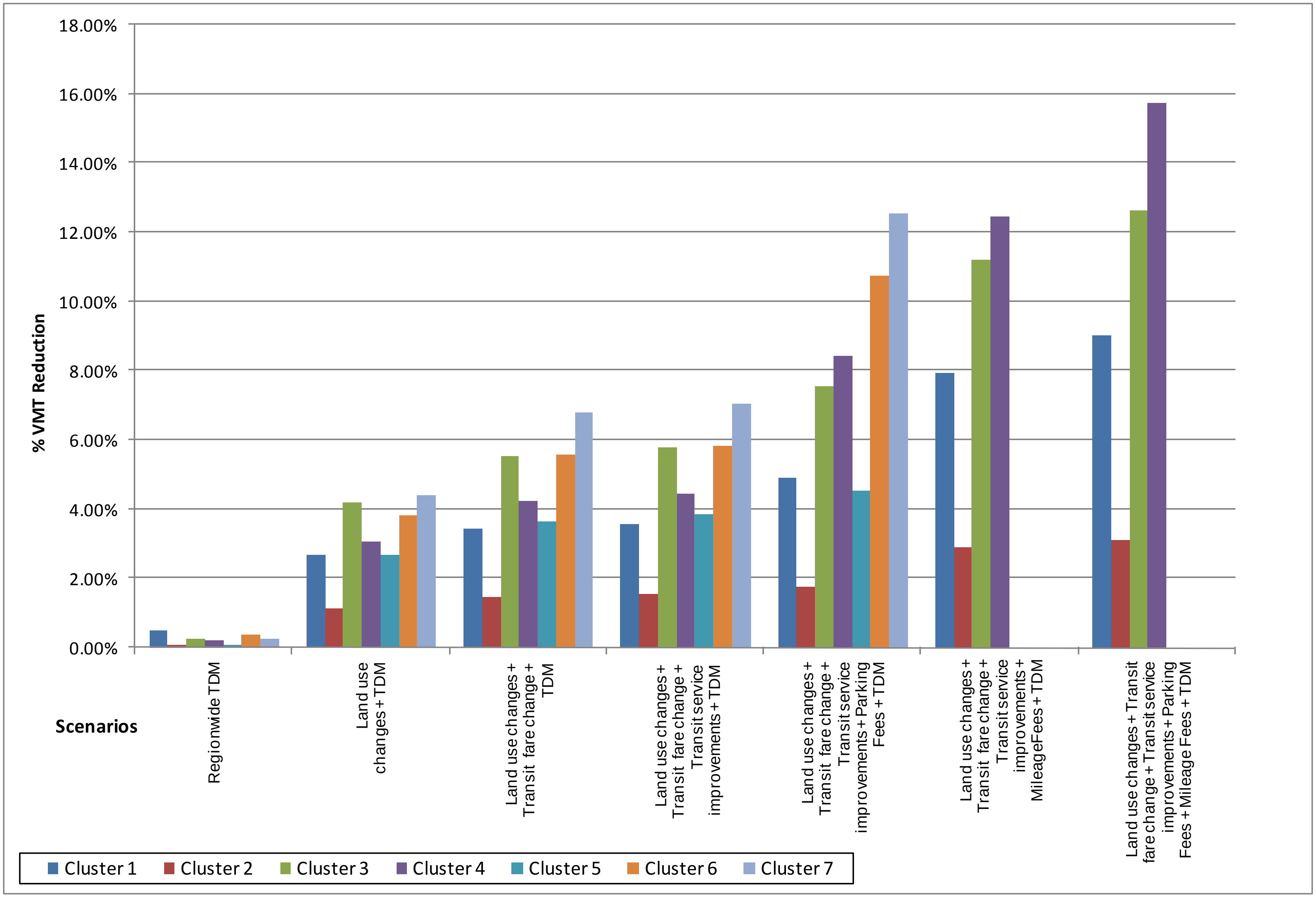
Figure 3 is useful in illustrating how the results may be used at the regional level. This graph shows how each cluster responds individually to the scenarios rather than collectively. In order to effectively use this information, the region must first recall the analysis methodology. The VMT reduction for two representative regions (three regions for Cluster 6) was averaged to provide the cluster response. This combines regional characteristics such as trip length, mode share, and other factors to describe an average region as the cluster surrogate. Therefore, to interpret the figure correctly, the user must consider the input and assumptions data in Appendix A. There are many possible interpretations for the differences observed. In order to make any strong conclusions, more detailed study is needed at the regional level. The following analysis provides an example of how to use this figure.

> *Cluster 2 has a mild response across all scenarios because the growth in VMT projected for the future year in that cluster is much lower than other clusters (33% growth in VMT from current year, as compared to most other clusters that project a growth of 70-80%). Like Cluster 2, Cluster 6 cities also project a growth in VMT lower than the other clusters (35%), however because cities in Cluster 6 have a very high auto drive alone mode share, their response to most of the TCMs is greater than Cluster 2. Cluster 7 has the highest auto drive alone mode share of all clusters, and parking costs that are at the lower end of a wide range. For this reason Cluster 7 shows a high response when parking charges are added in Scenario 5.*

Although this interpretation of the results provides a reasonable explanation, there may be other reasons that these clusters respond as illustrated. In a collective way the clusters provide an anticipated response that compares with other national-level studies; however, when disaggregated in this way, the factors combine and work with each other to create more information for consideration. Because the results of this study were focused on the national perspective, there has been no additional analysis to validate or otherwise compare these differences.

The analysis provides the ability to make comparisons between scenarios in order to identify lessons learned. The following information may assist in identifying how strategies may be used most effectively in individual situations.

Figure 3. Cluster Response to Scenarios in 2050



1. **Region-wide TDM Programs**

For this study, the assumptions regarding the application of TDM strategies were generally conservative. However, some experts have argued that a higher percentage of employer participation is reasonable to assume. Region-wide TDM programs were modeled separately because they were assumed to apply only to work trips and to a subset of the population – employed persons – while all other strategies applied to all trips made by the total population of the region. The TDM programs considered included flexible work hours, incentives for carpooling, ridematching programs, guaranteed ride home programs, subsidies for transit, pedestrian and bicycle modes, and telecommuting programs. The impact of TDM strategies appears to depend on several factors including population growth, shares of other modes relative to autos, and trip lengths. All of these factors trade off against each other in determining the impacts. For example, regions that experience slow population growth may see a higher impact of certain strategies than regions with higher population growth if the auto mode shares and vehicle trip lengths of the slow-growing regions are higher. Regions that on average already have relatively higher mode shares for auto rideshare, transit, bicycling, and walking, compared to auto drive alone mode shares, shorter trip lengths, and lesser growth expected in working population show a lower impact. These include Clusters 2-5. Average trip lengths may also play a role. Regions that project a high growth in population and have high auto drive alone mode shares are at the higher end of the range, such as those in Clusters 6 and 7. It must be noted that the impacts of TDM are influenced by the mode shares of vanpool, transit, non-motorized transport, and other modes because the TDM strategies included those that incentivize these modes. However, in many regions, mode shares for vanpool, walking and bicycling are not included in the travel demand models and were not provided. This is a limitation in the results for this scenario. Since the impact of this scenario on national VMT is very small, this limitation is not expected to affect the results in any significant way.

2. **Land Use Changes and Region-wide TDM Programs**

Greater VMT reduction from TDM programs and land use changes is expected in larger regions, especially those that have relatively longer trip lengths and project significant population growth. These factors differ in the different regions and trade off against each other to determine impacts. For example, Cluster 2 and Cluster 3 regions have similar average auto mode shares and similar average trip lengths; however, the impacts of land use strategies appear to be greater in Cluster 3 regions due to the higher expected growth in population. Higher growth implies greater potential reductions that may be expected from strategies involving densification and trip reduction through mixing of land uses. In Cluster 1 cities, while population growth is expected to be slow, the longer than average trip lengths imply a greater impact from land use and TDM strategies,

3. **Land Use Changes, Transit Fare Reduction Policies and Region-wide TDM Programs**

Greater reduction in VMT from the combined application of land use policies, transit fare reductions and TDM programs is expected in regions where the transit mode share is currently very low relative to drive alone auto mode share, where transit fares are higher than average, and where transit trip lengths are longer than average. One or more of these factors may play a role in determining the impacts of fare reduction through the application of subsidies. A much shorter transit trip length appears to lessen the impact of auto mode shares and transit fares in reducing VMT. The cluster 2 regions we selected have higher transit fares but relatively lower transit mode share and population growth rate than the other clusters. Even with fare subsidies, the travel costs do not reduce significantly in comparison to auto operating costs to make transit a more attractive mode for travelers; therefore, the reduction in VMT in response to transit fare reduction is lower in Cluster 2 than the other clusters. In Cluster 7 on the other hand, the combination of an already low transit fare with the lowest (almost negligible) transit mode share and large growth rate implies that a strategy that makes transit more attractive by further lowering fares would have a larger impact compared to the other clusters. Overall, existing transit mode share, fares, and population growth rates seem to determine impacts in this scenario, given that average transit trip length is similar across clusters.

4. Land Use Changes, Transit Fare Reduction Policies, Transit Service Improvements and Region-wide TDM Programs

In the presence of transit fare policies, the addition of transit service improvements (increase in frequency and/or reduction in travel times) into the scenario did not show a significant additional reduction in VMT across regions. The VMT reduction in this scenario was very similar to the results for Scenario 3. The factors responsible are similar to those discussed above, most importantly the relative mode shares of auto and transit modes. Where data on future year transit travel times were not provided, the assumption of the same baseline travel time as the current year was used. In general, the difference between base and future year travel times was insignificant in regions that provided the data.

5. Land Use Changes, Transit Fare Reduction Policies, Transit Service Improvements, Parking Charges and Region-wide TDM Programs

The introduction of parking charges into the scenario leads to a relatively broad range of expected VMT reductions, reflecting key differences between clusters. Higher reduction in VMT is seen in regions that have relatively higher auto mode shares and lower parking costs. Cluster 7 regions have the lowest daily parking costs on average. These regions are expected to experience the highest VMT reductions (in percentage) from a fixed increase in daily parking charges due to their high auto-drive alone mode share. Cluster 2 regions show the lowest reduction in VMT because of already high average daily parking charges and a relatively low auto drive-alone mode share. The same is true for Cluster 5 regions, although the impact is tempered by a higher population growth rate in these regions than in Cluster 2. Comparing results in Clusters 1 and 4, we find that despite similar average auto mode shares, a higher growth rate and lower existing parking charges in Cluster 4 result in a greater effect of this scenario in Cluster 4 regions.

6. Land Use Changes, Transit Fare Reduction Policies, Transit Service Improvements, Mileage Fees and Region-wide TDM Programs

At the lowest end of the range of VMT reduction for this scenario are the Cluster 2 regions, where auto drive-alone mode shares and population growth rates are lower than average. Despite similar average values for auto mode shares and trip lengths, Clusters 2 and 3 show a dramatically different response in this scenario. Cluster 3 shows a much higher impact due to a higher population growth rate (almost double that of Cluster 2) and a lower existing auto trip cost. Cluster 4 has a similar growth rate as Cluster 3, but higher auto drive-alone mode share and lower trip costs, making the impact slightly higher.

7. **Land Use Changes, Transit Fare Reduction Policies, Transit Service Improvements, Parking Fees, Mileage Fees and Region-wide TDM Programs**

The inclusion of one or more automobile pricing strategies widens the range of impacts, thus reflecting several regional differences. For the reasons discussed above, Cluster 4 regions show the largest reduction in VMT, while Cluster 2 regions show the smallest reduction.

4.3 Conclusion

The intent of this study was to use reasonably comparable data in a consistent analysis methodology to estimate the impacts of various transportation control measures. The results indicate that there are many factors that contribute to the ability to reduce VMT and emissions. The interactions of the different impacts in different regional types are strongly illustrated by the graph of the individual cluster responses to each scenario. This implies that it will be difficult, if not impossible, to identify a strategy or scenario that performs consistently across all metropolitan regions. The attractiveness of TCM strategies is that they are most easily implemented and any degree of behavioral change is valuable, especially in light of the supporting role or synergistic effects when combined with other strategies. What works best in an individual region will be subject to the willingness of the public and policy makers to support change. The broad interest in the effectiveness of transportation and related strategies for addressing GHG represents an important dynamic that has not been seen on this scale previously. The purpose of this study is to inform that interest.

The results are reasonably compared to that of other national studies, although the study methodologies were quite different. This suggests that at the national level, understanding the potential for reductions may be moving toward consensus. At the regional level, where the differences in characteristics are more important, a more detailed analysis will be more informative. If the national level understanding represents a new baseline of what might be achieved, the next logical step would be to conduct true regional analyses to compare to this baseline and to measure localized reductions through corridor or subarea studies where the more realistic impacts of land use, TDM, and transit changes can be seen.

While more detailed analysis at the regional level is desirable in order to gain a greater understanding of how these strategies could play out for specific areas, using this methodology with region-specific data and assumptions can provide an interim assessment of the effectiveness of individual and grouped strategies. The results obtained can help narrow the focus of more detailed and costly analysis as well as assist areas as they consider GHG emission reduction targets. The methodology and results of this study are most applicable to support policy discussions at both the regional and national level. As illustrated by the results, all strategies have a contribution to make in efforts to reduce transportation-related emissions.

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Appendix A

The following are tables and figures illustrating the data and analyses for this study.

TRIMMS evaluates strategies that directly affect the cost of travel, like transit fare subsidies, parking pricing, pay-as-you-go pricing initiatives and other financial incentives. TRIMMS also evaluates the impact of strategies affecting access and travel times. The model allows the user to account for employer-based program support strategies, such as flexible working hours, teleworking, and guaranteed ride home programs. It allows the analyst to use local data or defaults from national research findings. The VMT impacts of a given mix of strategies are subsequently calculated.

TRIMMS is a sketch planning tool that can be used to analyze many types of strategies at a regional or sub-area scale. However, strategies involving construction of new infrastructure such as new HOV/HOT lanes, new transit lines, and new bicycle/pedestrian facilities, can be analyzed most effectively using a regional travel demand model. In the TRIMMS model, such strategies can be modeled using the change in travel times and travel costs that such strategies represent. The TRIMMS model does not use trip tables. It requires average regional mode shares, average trip lengths and travel time by mode, average vehicle occupancy, parking costs, and trip costs as inputs. The user can change the price and travel time elasticity values. The tool provides changes in mode shares, trips, and VMT as outputs.

Table A-1. Input Requirements and Output Capabilities for TCM Analysis Tools and Models										
	Spreadsheet-Based Tools/Methods						Models			
	Meta-analysis	EPA Commuter model	TRIMMS	CCAP-TEG	TCM Tools	TCM Analyst	TDM Evaluation Model	STEAM	MARKAL-MACRO	NEMS
INPUTS										
Population		X	X							X
Per capita income										X
New vehicle sales										X
Mode shares (no. of trips)	X	X	X	X	X	X	X	X		
Average vehicle occupancies by mode	X	X	X				X	X		
Travel times by mode (in-vehicle and out-of-vehicle)		X	X				X	X		
Average trip costs by mode (including parking, fees, tolls, fuel costs, transit fares)	X	X	X				X	X		X
Includes non-motorized trips	X	X	X	X				X		
Average trip lengths	X	X	X	X		X				
Baseline regional VMT		X			X				X	X
Trip tables							X	X		
Baseline vehicle speeds	X	X			X	X				
Vehicle fleet mix	X	X							X	X
Fuel price per gallon	X			X					X	X
Average fuel economy	X			X						X
Emissions factors	X					X				
OUTPUTS										
Change in mode shares (no. of trips by mode)	X	X	X		X	X	X			
Change in travel time								X		
Change in VMT	X	X	X	X	X	X	X	X	X	X
Change in emissions	X	X		X	X	X		X	X	X
Change in speeds					X	X				
Fuel demand									X	X
Benefits and costs			X					X		

Table A-2. Assessment of Methods for Analyzing Travel Impacts of Transportation Control Measures (TCMs)								
	Methodologies / Models	Developer	Last Update	Inputs Required	Outputs	Scale of Analysis (sub-area, regional, national)	TCMs Modeling Capability	Limitations
1	Travel Demand Management (TDM) Evaluation Model	COMSIS and R.H. Pratt Consultants for FHWA	1993	Base case trip tables, vehicle occupancy, model coefficients (in-vehicle time, out-of vehicle time, transit time, transit fare, parking cost, HOV time saved), mode shares, and information about TCMs	Change in VMT and trips	Sub-area and with limited capability, regional	Following TCMs cannot be modeled: ▪ Land use strategies. ▪ Incentives for bicycle use and pedestrians. ▪ Travel time changes (alternative work hours or peak period pricing). ▪ Some pricing strategies, e.g., distance-based pricing and fuel price changes.	▪ Has not been updated, although user can input new model coefficients. ▪ Does not account for NMT trips. ▪ Only evaluates home-based work trips for large regions. ▪ Cannot model distance-based strategies. ▪ Does not appear to have been used recently.
2	EPA's Commuter model	Sierra Research; updated by Cambridge Systematics	2005	Population, mode shares, trip lengths, occupancy levels, baseline VMT, baseline speeds, mode choice time and cost coefficients, fleet mix, and details about the TCMs	Change in mode shares, trips and VMT, and emissions impacts (based on emissions factors in EPA's MOBILE 6.2 model)	Sub-area and regional, with some adjustment	Cannot model: ▪ Regional land use strategies and any TCMs that will change regional travel patterns. ▪ TCMs that affect vehicle speeds. ▪ Location-specific strategies such as area-wide pricing and higher parking charges in certain areas.	▪ In order to analyze strategies in a large region, separate geographic areas must be defined that have somewhat homogenous travel characteristics such as mode shares and travel distances.

Table A-2. Assessment of Methods for Analyzing Travel Impacts of Transportation Control Measures (TCMs)								
	Methodologies / Models	Developer	Last Update	Inputs Required	Outputs	Scale of Analysis (sub-area, regional, national)	TCMs Modeling Capability	Limitations
3	Trip Reduction Impacts for Mobility Management Strategies (TRIMMS) model	Center for Urban Transportation Research, University of South Florida	2009	No trip tables. Needs average regional mode shares, average trip length and travel time by mode, average vehicle occupancy, parking and trip costs, and details about the TCMs	Changes in mode shares, trips, VMT, and emissions	Sub-area and regional, with some adjustment Practitioner-oriented sketch planning tool to measure travel impacts of regional and employer-based TCMs.	▪ Can model any strategy that affects the cost of using existing modes or travel times. ▪ Can model packages of strategies. The user can change price and travel time elasticity values.	▪ Cannot model regional land use/smart growth strategies accurately. The user will have to make assumptions about the effects of land use strategies on trip lengths or travel times in order to model these strategies.
4	Surface Transportation Efficiency Analysis Model (STEAM)	Cambridge Systematics	2006	Base case and improvement case trip tables, vehicle occupancy, model coefficients (trip time and cost), mode shares, and TCM characteristics (in terms of change in trip costs or travel time).	Change in VMT and person miles traveled, trips, travel time, and emissions	Regional and sub-area/corridor	Most TCMs can be modeled.	▪ Much data and effort required from agencies to model TCMs using demand models. ▪ Only a few test cities can be considered because extensive data inputs are required for STEAM.
5	Transportation Emissions Guidebook (TEG)	Center for Clean Air Policy (CCAP)	2006 (?)	Number of trips by mode, mode split, trip lengths	VMT and Emissions	Regional and Sub-area	Spreadsheets providing rule of thumb guidance on impacts of TCMs based on literature; most TCMs can be modeled.	▪ The user has to make several assumptions. ▪ Cannot estimate mode shift or trip reduction impacts.
6	TCM Tools	Sierra Research	Early 1990s	Has separate Transportation and Emissions modules –	Changes in mode share, vehicle-trips, VMT, travel	More applicable at regional scale; some sub-area policies can	Wide range of strategies can be modeled, including land use	▪ Spreadsheet-based sketch-planning tool.

Table A-2. Assessment of Methods for Analyzing Travel Impacts of Transportation Control Measures (TCMs)								
	Methodologies / Models	Developer	Last Update	Inputs Required	Outputs	Scale of Analysis (sub-area, regional, national)	TCMs Modeling Capability	Limitations
				trips, VMT, speed	speeds, and emissions	be modeled	strategies, but cannot model scenarios well	▪ User must make many assumptions to calculate travel impacts. ▪ Emissions module cumbersome to run.
7	TCM Analyst	Texas Transportation Institute	1994; will hear about updates from TTI on 12/5/08	Trips, distances, speeds, emissions factors, TCM details	Changes in trips, VMT, average travel speeds, and emissions	Regional or sub-area	Pricing strategies cannot be modeled	▪ Elasticities and other assumptions must be defined by the user. ▪ Land use and pricing strategies cannot be modeled ▪ Sketch planning tool.
8	MARKAL (Market Allocation)-MACRO	US DOE and EPA	Used internationally and currently in use	Baseline VMT by vehicle type, fuel costs	VMT, emissions, and fuel demand	National	TCMs relevant at sub-area, urban, or state level cannot be modeled	▪ More complicatedand not as detailed as NEMS. ▪ Can only model national level TCMs such as fuel taxes, emissions taxes.
9	National Energy Modeling System (NEMS): Transportation Sector Module (TRAN)	Energy Information Administration, US DOE	2006	Vehicle fleet (includes transit and freight), fuel prices, fuel economy, passenger miles, change in user cost, population, income, new vehicles sales	VMT, emissions, and fuel demand	Census region and national	Cannot model: ▪ TCMs relevant at sub-area, urban, or state level ▪ TCMs involving mode switching ▪ Includes useful feedback effects, and can be used to validate national	▪ Will model strategies at the level of nine Census regions, not at urban or sub-region level. ▪ Can only models TCMs that affect the user cost of travel; for others, some meta-analysis is

Table A-2. Assessment of Methods for Analyzing Travel Impacts of Transportation Control Measures (TCMs)								
	Methodologies / Models	Developer	Last Update	Inputs Required	Outputs	Scale of Analysis (sub-area, regional, national)	TCMs Modeling Capability	Limitations
							estimates	required before using NEMS. ▪ Change in modes not easy to model
10	Spreadsheet analysis with elasticity factors from literature		--	Mode shares, trip costs by mode, average VMT	VMT change – followed by emissions analysis	Regional	Without trip tables, land use strategies are best modeled this way	

Table A-3. Quantitative Estimates of Travel Activity Impacts of TCMs from Literature

Examples of Measures	Elasticity/ VMT Reduction %
Ridesharing Programs and Investments	
Park-and-ride facilities	Regional implementation: 0.1 to 0.5% reduction in VMT
High-Occupancy Vehicle (HOV) lanes	Long run (LR) travel time elasticity, regional: -1.0, urban: -0.6, rural: -1.3 0.2 to 1.4% VMT reduction
Rideshare matching programs	0.1 to 2.0% VMT reduction
Carpool/vanpool incentives	0.2 to 3.3% VMT reduction
Car-sharing	Limited quantitative data
Bicycle and Pedestrian Facilities and Programs	
Bike paths / lanes / routes	<0.1% VMT reduction
Bike/ped facilities to support transit	Limited quantitative data
Transit Projects and Policies	
Transit service expansion /increase in frequency	-0.6 to -1.0; for buses -0.5 (time between buses) for service frequency alone
Improved transit travel times and operations (busways, BRT, signal prioritization for transit vehicles, heavy and light rail, managed lanes)	-0.4 (travel time elasticity with respect to ridership)
Improved transit access through shuttle and feeder bus services, paratransit	Relates to improving travel time above, not measured separately
Transit service integration and intermodal transfer centers	Relates to improving travel time above
Fare integration for easy transfers	Relates to improving travel time above
Improved transit marketing, information, amenities	Limited quantitative data
Commuter discounts/fare reductions	-0.3 to -0.4 (fare elasticity with respect to ridership)
Peak/off-peak transit fares	-0.1 to -0.3 (peak fares) and -0.1 to -0.7 (off-peak fares, depending on trip purpose; lower for work trips)
Transit improvement policies, overall	Studies estimate 0 to 2.6% VMT reduction
Parking Management and Incentives	
Parking cash-out	Elasticities are not available; although some quantitative data on percentage reduction in regional VMT are available from specific projects and studies.
Preferential parking for carpools and vanpools	
Parking duration restrictions	
Employer-based Programs (effects depend on level of adoption)	
Flexible work schedules	Elasticities are not available; although some quantitative data on percentage reduction in regional VMT are available from specific projects and studies.
Telecommuting	
Compressed work weeks	
Employer-provided transit passes	
Guaranteed ride home programs	

Table A-3. Quantitative Estimates of Travel Activity Impacts of TCMs from Literature	
Examples of Measures	Elasticity/ VMT Reduction %
Pricing Policies	
Area-wide road pricing/congestion pricing	-0.1 to -0.4 (urban road pricing); 10-25% reduction in central city VMT with cordon pricing; 0.2 to 5.7% regional VMT reduction
Distance-based pricing or mileage fees	LR: -0.1 to -0.8 (price elasticity). Conservative LR estimate for the U.S. would be -0.3
Peak period pricing/ variably priced lanes	-0.03 to -0.4 (depending on time of day)
Parking pricing/fees	Overall LR elasticity: -0.1 to -0.5 LR regional: -0.3; at sites: -0.1 to -0.2 LR (non-commute): -0.2 to -0.4 Studies show 0.5-4% reduction in work-related VMT; 3.1 to 4.2% reduction in non-work VMT
High Occupancy Toll (HOT) lanes/toll increases	-0.1 to -0.4; data from specific projects are available
Pay-as-you-drive Insurance	-0.3
Fuel taxes	LR: -0.1 to -0.3, tending towards the lower end
Freight vehicle pricing	-0.25 to -0.35 (price elasticity); -0.3 to -0.7 (travel time elasticity)
Integrated Land Use and Transportation Strategies	
Transit-oriented development and incentives (Design and transit access)	-0.05 (vehicle trips) and -0.03 to -0.08 (VMT)
Smart growth and mixed use development (Diversity)	-0.03 (vehicle trips) and -0.05 (VMT)
Land use controls for compact, dense urban development (Density)	-0.05 (vehicle trips) and -0.05 to -0.12 (VMT)
Improved regional accessibility due to combined measures	-0.18 to -0.22 (VMT); studies estimate regional VMT reduction by 2-20% in 20 years with doubling of results in 40 years.
Land use measures, overall	Regional VMT reduction of 0 to 5.2%
Vehicle Restrictions by Geographic Area or in Peak Periods	
Freight vehicle controls	Elasticities are not available; although some quantitative data on percentage reduction in regional VMT are available from specific projects and studies.
No-drive days	
Urban non-motorized zones	
Public Education and Outreach Programs	
TDM outreach programs by employers	These measures are typically implemented as part of other measures. Difficult to estimate impacts separately as it could lead to double-counting.
Episodic programs (e.g. ozone action days)	
Public communication about the impacts of travel decisions	

Table A-4. Fare and Price Elasticities used in TRIMMS				
	Elasticity			
Mode	Short run	Long run	Source	Notes
Auto - Drive Alone				
Direct	-0.11	-0.22	Litman (2010)	Table 22, pp.27 (TRIMMS default); long run auto drive alone elasticity assumed double of short run elasticity
Cross-Price: Transit	0.05	0.05	Litman (2010)	TRIMMS default uses the lower ranges; long run elasticity assumed same as short run since no better information available
Auto - Rideshare				
Direct	n/a	n/a		Assumed zero since no information is available
Cross-Price: Transit	0.05	0.05	Litman (2010)	Same long run elasticity as auto-drive alone assumed
Vanpool				
Direct: Peak	-0.16	-0.16		TRIMMS default; no information about short run vs. long run vanpool elasticities, so assumed same
Direct: Off-peak	-0.32	-0.32		
Cross-Price: Transit	0.05	0.05		TRIMMS default
Transit				
Direct: Peak	-0.10	-0.10		TRIMMS default; no information about short run vs. long run transit elasticities, so assumed same
Direct: Off-Peak	-0.30	-0.30		TRIMMS default
Cross-Price: Auto Drive Alone	0.15	0.15	Litman (2010)	TRIMMS default uses the lower ranges
Cross-Price: Auto Rideshare	0	0.15		Long run elasticity assumed same as auto drive alone

Source: Adapted from Concas and Winters (2009) and from TRIMMS model version 2.0 received from CUTR on July 15, 2009 pp 44-46

Table A-5. Travel Time Elasticities			
Mode	Elasticity		Notes
	Peak	Off peak	
Auto - Drive Alone			TRIMMS default assumptions
Direct	-0.225	-0.170	
Cross: Auto -Rideshare	0.037	0.001	
Cross: Transit	0.036	0.001	
Auto - Rideshare			
Direct	-0.303	-0.189	
Cross: Auto -Drive Alone	0.030	0.000	
Cross: Transit	0.030	0.000	
Vanpool			
Direct	-0.60	n/a	
Cross-Price: Auto -Rideshare/Drive Alone	n/a	n/a	
Cross: Transit	0.032	0.000	
Transit			
Direct	-0.129	-0.074	
Cross: Auto -Drive Alone	0.010	0.000	
Cross: Auto -Rideshare	0.032	0.000	

Source: Litman (2010)Table 31, pp. 35

Table A-6. Parking Pricing Elasticities				
Parking Elasticities				
Trip Purpose	Auto – Drive Alone	Auto - Rideshare	Transit	Slow Mode
Commuting	-0.08	-0.02	-0.02	-0.02

Source: Litman (2010), Table 13, pp. 17

Table A-7. Summary of Populations, Calculations & Correction Factors

	Summary of Populations, Calculations & Correction Factors														
	Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5		Cluster 6			Cluster 7	
	Pop > 2.9mil ; Trns > 9%		Pop > 2.9mil ; Trns < 9%		Pop > 1.5mil ; Trns > 4%		Pop > 1.5mil ; Trns > 4%		Pop > 750K		Pop > 250K			Pop < 250K	
	San Francisco	Washington DC	San Diego	Seattle	Denver	Portland	Sacramento	Salt Lake City	Memphis	Raleigh-Durham	Fresno	Knoxville	Rochester	Burlington	Wilmington
POPULATIONS & TRANSIT MODE SHARES															
2000 Census Pop	2,995,291	3,932,927	2,674,996	2,712,338	1,984,585	1,582,863	1,394,615	887,916	971,282	828,683	554,815	420,081	693,863	105,573	161,079
2007 FHWA UA Pop	3,162,000	4,332,000	2,951,000	3,108,000	2,184,000	1,805,000	1,858,000	970,000	1,035,000	949,000	641,000	488,000	745,000	135,000	194,000
MPO Provided Values[1]															
Modeled Total BY Pop	7,159,379	6,808,844	3,089,035	3,695,516	2,685,000	1,961,153	1,936,006	1,933,000	1,103,539	1,312,000	992,997	862,903	823,147	147,000	226,961
Modeled Working BY Pop	3,282,403	3,547,408	2,399,837	1,934,713	2,120,000	1,032,246	1,407,816	1,029,000	533,378	683,000	415,840	429,939	422,942	116,000	112,845
Modeled Total FY Pop	9,031,498	8,282,368	3,984,753	4,988,135	4,388,529	3,097,402	3,349,000	2,820,000	1,499,124	2,647,000	1,402,217	1,306,460	868,076	212,000	430,154
Modeled Working FY Pop	5,016,501	4,315,114	3,098,248	2,789,293	3,322,116	1,799,152	1,546,000	1,575,000	745,973	1,332,000	609,437	872,930	446,027	174,000	221,344
TRIMMS Modeled Values[2]															
TRIMMS BY Pop Input	3,282,403	3,547,408	2,399,837	1,934,713	2,120,000	1,961,153	1,407,816	1,029,000	533,378	683,000	415,840	429,939	422,942	116,000	112,845
TRIMMS FY Pop Input	5,015,512	4,315,114	3,098,248	2,789,293	3,322,116	3,097,402	1,546,000	1,575,000	745,973	1,332,000	609,437	872,930	446,027	174,000	221,344
TRIMMS BY TDM Pop Input	984,721	1,064,222	719,951	580,414	636,000	588,346	422,345	308,700	160,013	204,900	124,752	128,982	126,883	34,800	33,854
TRIMMS FY TDM Pop Input	2,507,756	2,157,557	1,549,124	1,394,647	1,661,058	1,548,701	773,000	787,500	372,987	666,000	304,719	436,465	223,014	87,000	110,672
Transit Mode Shares[3]															
CTPP 2000 (Urbanized Area)	16.0%	13.0%	4.0%	8.0%	5.0%	7.0%	3.0%	4.0%	1.95%	2.69%	2.09%	0.66%	2.89%	2.0%	1.0%
MPO Provided Values	5.3%	4.5%	1.5%	2.9%	2.0%	3.3%	3.3%	1.3%	1.0%	1.2%	1.2%	1.0%	0.8%	0.7%	0.02%
VMT Shares[4]															
Share of FHWA estimated national VMT based on FHWA 2007 Pop and CTPP 2000 transit share	17%		22%		6%		7%		12%		18%			17%	
CALCULATIONS & CORRECTION FACTORS															
Trip Rate Calculations[5]															
2007 Daily VMT (FHWA)[7]	68,939,000	97,860,000	68,442,000	71,358,000	52,735,000	35,211,000	34,838,000	22,317,000	26,900,000	35,108,000	11,967,000	16,050,000	16,742,000	3,211,000	5,273,000
MPO Provided Auto Trip Length	11.8	10.8	7.12	12.8	11.4	6.6	12.5	7.1	11.04	7.26	11.8	8.1	8.1	11.8	3.42
Calculated Daily # of Trips	5,842,288	9,061,111	9,612,640	5,574,844	4,625,877	5,335,000	2,787,040	3,143,239	2,436,594	4,835,813	1,014,153	1,981,481	2,066,914	272,119	1,541,813
Calculated Daily Trip Rate	1.8	2.1	3.3	1.8	2.1	3.0	1.5	3.2	2.4	5.1	1.6	4.1	2.8	2.0	7.9
Researched Trip Rate	3.0				3.8	3.1	4.1			4.2	2.0	3.5			4.3
Correction Factors[6]															
Modeling Correction Factor-BY	2.18	1.92	1.29	1.91	1.27	1.00	1.38	1.88	2.07	1.92	2.39	2.01	1.95	1.27	2.01
Modeling Correction Factor-FY	1.80	1.92	1.29	1.79	1.32	1.00	2.17	1.79	2.01	1.99	2.30	1.50	1.95	1.22	1.94
Trips Correction Factor	1.48	1.05	1.63	0.90	1.90	1.57	2.04	1.62	1.18	2.10	1.00	1.73	1.39	1.01	2.13
Population Correction Factor	1.84	1.57	2.00	2.06	1.94	1.94	1.86	2.13	2.14	1.77	2.23	2.04	1.86	1.92	2.02
FINAL Correction Factor-BY	5.95	3.15	4.19	3.53	4.67	3.04	5.22	6.48	5.21	7.12	5.33	7.06	5.02	2.45	8.63
FINAL Correction Factor-FY	4.91	3.15	4.19	3.30	4.87	3.04	8.22	6.18	5.06	7.37	5.13	5.27	5.02	2.36	8.34
FINAL TDM Correction Factor	1.84	1.57	2.00	2.06	1.94	1.94	1.86	2.13	2.14	1.77	2.23	2.04	1.86	1.92	2.02

(1) These are the population figures provided by the MPOs.
(2) These are the values that were used for the TRIMMS model runs.
(3) These are the transit shares available from the 2000 CTPP Urbanized Areas and the shares provided by the MPOs for their whole modeled areas.
(4) This is the share of national VMT (estimated by FHWA for 2007 VMT); dividing cities throughout the country into clusters based on their FHWA 2007 Urbanized Area population and 2000 CTPP transit shares.
(5) Trip rates were calculated using 2007 VMT estimated by FHWA, trip lengths provided by the MPOs and the 2007 Urbanized Area population estimated by FHWA. Trip rates were also researched for each MPO using various documents and studies available on the MPOs' websites. Where a researched trip rate was found, it was used for the correction factors; otherwise the calculated trip rate was used.
(6) To adapt the results obtained from the TRIMMS model for our analysis, we applied the following three correction factors. (1) All TRIMMS model runs were originally run using working population instead of total population. The MODELING CORRECTION FACTOR adjusts for this difference. (2) Since TRIMMS focuses on employee travel behavior, it always assumes a trip rate of two trips per person per day (assuming a worker goes from his home to the employer site and back home). Our study covers all trip purposes and attempts to nullify this assumption by adjusting the trip rate (i.e. by multiplying the TRIMMS model outputs by the best known trip rate for each urban area and dividing by 2). (3) TRIMMS also makes an assumption that only a subset of the population will be affected by these TDMs. To nullify this assumption, the TRIMMS model outputs were also multiplied by the ratio of Total MPO Provided Population to TRIMMS Affected Population.
(7) Data on daily VMT from FHWA's Highway Statistics (2007) does not include travel on interstates. These data were used to estimate daily trip rate where trip rates were not available and for calculating each cluster's share of national VMT.

Table A-8. Data from MPOs and Other Sources

	MPO Provided Values - All TRIMMS Model Inputs															
	Cluster 1				Cluster 2				Cluster 3				Cluster 4			
	Pop > 2.9mil ; Trns > 9%				Pop > 2.9mil ; Trns < 9%				Pop > 1.5mil ; Trns > 4%				Pop > 1.5mil ; Trns > 4%			
	San Francisco		Washington DC		San Diego		Seattle		Denver		Portland		Sacramento		Salt Lake City	
	BY	FY	BY	FY	BY	FY	BY	FY	BY	FY	BY	FY	BY	FY	BY	FY
Model Years	2006	2035	2010	2030	2006	2030	2006	2040	2008	2040	2005	2035	2005	2030	2005	2030
Peak Hour Trips (%)	54	52	42	42	50	30	50	50	50	50	50	31	50	50	43	43
Vehicle Occupany	1.34	1.31	1.25	1.26	1.00	1.00	1.00	1.00	1.33	1.32	2.30	1.37	1.32	1.29	2.50	2.48
Populations																
Modeled Total Pop	7,159,379	9,031,498	6,808,844	8,282,368	3,089,035	3,984,753	3,695,516	4,988,135	2,685,000	4,388,529	1,961,153	3,097,402	1,936,006	3,349,000	1,933,000	2,820,000
Modeled Working Pop	3,282,403	5,015,512	3,547,408	4,315,114	2,399,837	3,098,248	1,934,713	2,789,293	2,120,000	3,322,116	1,032,246	1,799,152	1,407,816	1,546,000	1,029,000	1,575,000
Change in Total Pop	26%	1,872,119	22%	1,473,524	29%	895,718	35%	1,292,619	63%	1,703,529	58%	1,136,249	73%	1,412,994	46%	887,000
Change in Working Pop	53%	1,733,109	22%	767,706	29%	698,411	44%	854,580	57%	1,202,116	74%	766,906	10%	138,184	53%	546,000
Mode Shares																
Auto-drive alone	61.54	62.30	75.50	75.20	52.00	51.50	43.40	43.70	51.00	53.00	45.60	44.50	91.90	88.80	42.46	41.75
Auto-rideshare	21.28	20.20	20.00	19.60	42.90	43.70	43.30	40.00	44.00	42.00	40.70	40.20	-	-	47.26	47.50
Public transit	5.29	6.10	4.50	5.20	1.50	1.60	2.90	4.30	2.00	2.00	3.30	4.20	3.30	3.60	1.29	2.45
Cycling	1.70	1.50	-	-	0.20	0.20	5.20	6.00	-	-	1.00	1.10	2.40	3.80	4.49	4.15
Walking	10.19	9.90	-	-	2.60	2.40	5.20	6.00	-	-	6.50	7.20	2.40	3.80	4.50	4.15
Other	-	-	-	-	0.80	0.60	-	-	3.00	3.00	3.00	2.90	-	-	-	-
Trip Lengths (miles)																
Auto-drive alone	11.8	11.9	10.8	10.9	7.1	7.0	12.8	12.8	11.4	13.3	6.6	6.2	12.5	12.5	7.1	7.7
Auto-rideshare	11.8	11.9	10.8	10.9	6.0	6.5	12.8	12.8	11.4	13.3	6.6	6.2	12.5	12.5	6.3	6.8
Public transit [1]	11.8	11.9	10.3	10.4	6.9	7.5	12.8	12.8	11.4	13.3	6.9	6.9	12.5	12.5	9.7	11.6
Cycling [2]	-	-	-	-	1.7	1.7	-	-	-	-	2.5	2.6	-	-	2.0	2.0
Walking [3]	-	-	-	-	0.9	0.9	-	-	-	-	1.4	1.3	-	-	2.0	2.0
Other [4]	-	-	-	-	7.5	7.2	-	-	-	-	2.7	2.5	-	-	7.1	7.7
Travel Times (minutes)																
Auto-drive alone	26.9	32.5	30.6	33.5	24.3	29.3	22.3	28.9	22.5	28.9	21.1	26.9	22.8	28.8	14.0	16.0
Auto-rideshare	26.9	32.5	30.6	33.5	27.1	32.7	0.0	32.1	26.6	34.2	24.5	31.3	26.1	33.0	13.0	15.0
Public transit	36.8	36.8	46.1	45.5	50.5	50.5	35.1	35.1	38.1	49.0	38.2	38.2	41.5	41.5	50.0	49.0
Cycling	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.7	17.7
Walking	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.7	17.7
Other [5]	18.3	18.3	-	16.4	17.1	17.1	-	18.0	17.0	21.9	19.7	19.7	-	15.4	-	-
Travel Costs																
Parking - drive alone	9.40	15.40	11.00	16.35	4.00	5.94	10.91	19.76	5.30	9.60	5.71	12.93	4.50	7.38	10.00	16.40
Parking - rideshare	7.00	11.80	8.79	13.00	4.00	5.94	10.91	19.76	4.00	7.30	2.48	9.44	3.40	5.70	4.00	6.60
Trip Cost - drive alone	2.71	2.70	1.30	1.31	0.96	1.22	1.84	1.84	1.80	2.50	0.60	0.81	1.90	2.34	0.92	1.25
Trip Cost - rideshare	2.02	2.01	1.02	1.01	0.81	1.14	1.84	1.84	0.91	1.90	0.26	0.59	1.40	1.80	0.33	0.50
Transit Fare	2.00	4.20	2.30	4.20	2.50	4.52	2.50	6.10	0.75	1.82	1.21	2.94	2.25	4.71	1.35	2.80

Notes:

BY: Base Year; FY: Future Year

Total population was used to analyze all scenarios, except Scenario 1 (TDM), which used Working Population

FY parking charges not available in most cases; assumed to increase by 2% based on guidance from Metropolitan Transportation Commission, San Francisco

FY transit fares not available in many cases; assumed to increase with inflation at 3% per year

Where data were not provided, FY travel times for drive alone and rideshare modes based on Texas Transportation Institute's projections for change in Travel Time Index between 2003 and 2030

BY transit fares and parking charges were obtained from MPO websites when not provided or from Colliers International Parking Rate Survey, available at: Colliers International Parking Rate Survey instead: http://www.colliers.com/content/globalcolliersparkingratesurvey2009.pdf

Default TRIMMS trip lengths used where trip length was not available by mode

Where FY trip lengths and auto operating costs not provided, these were assumed same as BY

Data not provided by MPOs are marked by "-"

(1) Used TRIMMS default public transit trip length of 12.2 where no data was provided by the MPO

(2) Used TRIMMS default cycling trip length of 2.9 where no data was provided by the MPO

(3) Used TRIMMS default walking trip length of 0.9 where no data was provided by the MPO

(4) Used TRIMMS default Other trip length of 12.2 where no data was provided by the MPO; for Salt lake City, Rochester, Raleigh-Durham and Wilmington, used auto drive alone trip length for "other" mode since TRIMMS default appeared too high for these cities

(5) In many cases, walk and bike travel times were not available; therefore, for consistency across cities, data from the American Community Survey 2005-2007 were used, available at: http://ctpp.transportation.org/profiles_2005-2007/ctpp_profiles.html. Since this source groups walk, bike, and other modes into the category "other", no separate travel times are given for walk and bike and the travel times listed above under "other" can be considered average across these modes

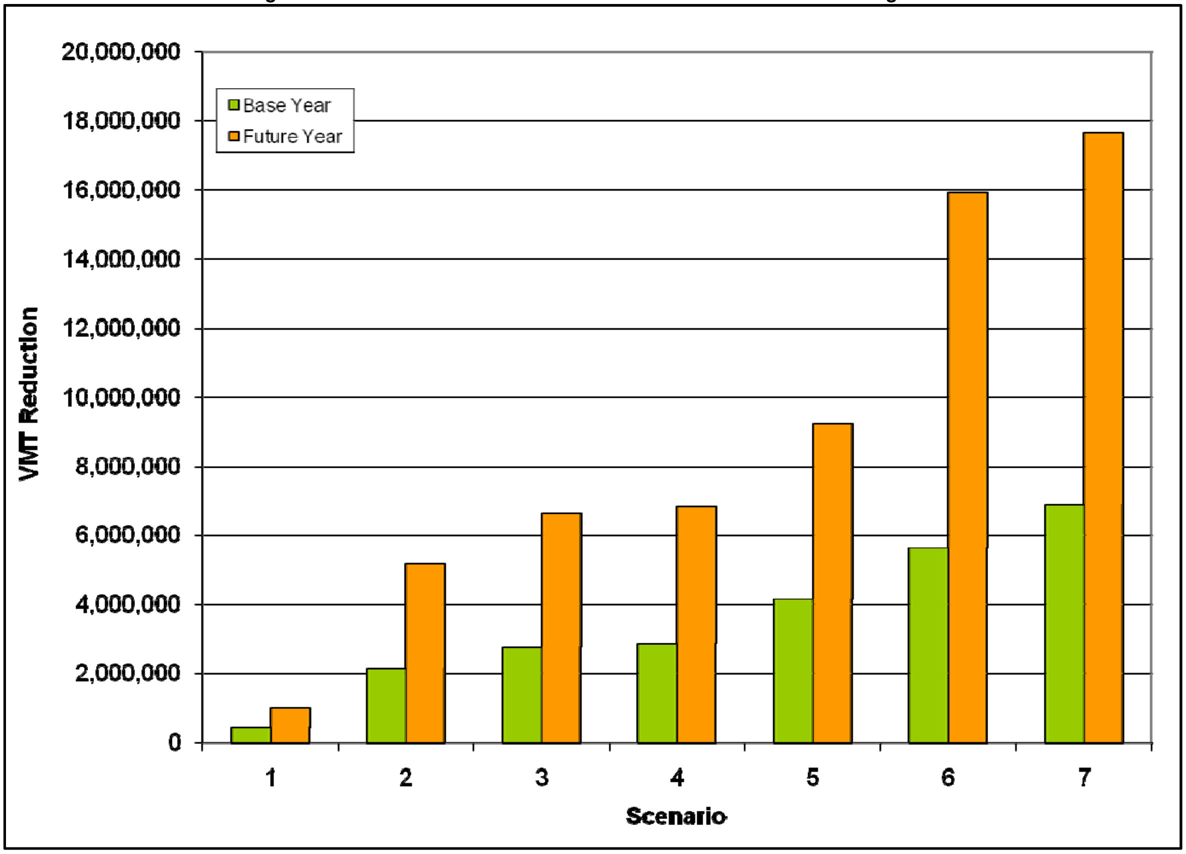
Table A-8. Data from MPOs and Other Sources

	MPO Provided Values - All TRIMMS Model Inputs													
	Cluster 5				Cluster 6						Cluster 7			
	Pop > 750K				Pop > 250K						Pop < 250K			
	Memphis		Raleigh-Durham		Fresno		Knoxville		Rochester		Burlington		Wilminton	
	BY	FY	BY	FY	BY	FY	BY	FY	BY	FY	BY	FY	BY	FY
Model Years	2004	2030	2005	2035	2010	2035	2006	2034	2005	2031	2000	2025	2008	2035
Peak Hour Trips (%)	51	51	47	46	50	50	47	47	15	16	50	50	17	17
Vehicle Occupany	2.21	2.13	1.29	1.29	1.00	1.00	1.70	1.70	1.24	1.25	1.00	1.23	1.00	1.00
Populations														
Modeled Total Pop	1,103,539	1,499,124	1,312,000	2,647,000	992,997	1,402,217	862,903	1,306,460	823,147	868,076	147,000	212,000	226,961	430,154
Modeled Working Pop	533,378	745,973	683,000	1,332,000	415,840	609,437	429,939	872,930	422,942	446,027	116,000	174,000	112,845	221,344
Change in Total Pop	36%	395,585	102%	1,335,000	41%	409,220	51%	443,557	5%	44,929	44%	65,000	90%	203,193
Change in Working Pop	40%	212,595	95%	649,000	47%	193,597	103%	442,991	5%	23,085	50%	58,000	96%	108,499
Mode Shares														
Auto-drive alone	45.00	47.00	54.00	54.00	96.90	97.20	72.00	72.00	92.27	92.47	91.80	92.30	99.98	99.98
Auto-rideshare	46.00	46.00	37.40	37.40	-	-	24.00	24.00	-	-	5.80	5.30	-	-
Public transit	1.00	0.50	1.20	1.20	1.20	1.10	1.00	1.00	0.82	0.80	0.70	0.70	0.02	0.02
Cycling	2.50	2.00	-	-	0.95	0.85	1.00	1.00	3.45	3.36	0.80	0.80	-	-
Walking	2.50	2.00	-	-	0.95	0.85	2.00	2.00	3.46	3.37	0.90	0.90	-	-
Other	3.00	2.50	7.40	7.40	-	-	-	-	-	-	-	-	-	-
Trip Lengths (miles)														
Auto-drive alone	11.0	12.1	7.3	7.5	11.8	11.8	8.1	8.1	8.0	8.1	11.8	11.8	3.4	2.6
Auto-rideshare	11.0	12.1	6.6	6.6	-	-	7.3	7.3	-	-	11.8	11.8	-	-
Public transit [1]	6.0	6.6	-	-	11.8	11.8	-	-	2.2	2.3	11.8	11.8	5.2	5.2
Cycling [2]	6.0	6.5	-	-	-	-	-	-	-	-	-	-	-	-
Walking [3]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other [4]	9.4	11.7	7.3	7.5	-	-	-	-	8.0	8.1	-	-	3.4	2.6
Travel Times (minutes)														
Auto-drive alone	21.4	22.5	14.4	15.8	19.0	21.6	20.0	22.7	15.5	15.9	20.1	21.1	27.0	29.2
Auto-rideshare	21.4	22.5	13.7	14.6	-	-	19.0	21.5	-	-	22.4	23.5	-	-
Public transit	14.5	15.1	34.3	39.5	37.8	37.8	17.0	19.3	31.8	32.5	33.2	33.2	25.0	25.0
Cycling	14.5	15.0	-	-	-	-	45.0	51.0	-	-	-	-	-	-
Walking	14.5	15.1	-	-	-	-	12.0	13.6	-	-	-	-	-	-
Other [5]	20.5	22.9	18.6	21.4	-	-	-	-	-	-	-	-	-	-
Travel Costs														
Parking - drive alone	8.00	13.40	11.00	19.90	2.95	4.84	8.00	13.90	3.60	5.91	4.00	5.94	2.00	3.30
Parking - rideshare	3.62	6.30	8.50	15.40	2.95	4.84	4.70	8.20	2.90	4.73	4.00	4.83	-	-
Trip Cost - drive alone	VMT fees not analyzed for Cluster 5 and below													
Trip Cost - rideshare														
Transit Fare	1.50	3.20	2.00	4.90	1.00	2.10	1.50	3.40	1.00	2.10	1.25	2.26	1.10	2.40

Notes:
BY: Base Year; FY: Future Year
Total population was used to analyze all scenarios, except Scenario 1 (TDM), which used Working Population
FY parking charges not available in most cases; assumed to increase by 2% based on guidance from Metropolitan Transportation Commission, San Francisco
FY transit fares not available in many cases; assumed to increase with inflation at 3% per year
Where data were not provided, FY travel times for drive alone and rideshare modes based on Texas Transportation Institute's projections for change in Travel Time Index between 2003 and 2030
BY transit fares and parking charges were obtained from MPO websites when not provided or from Colliers International Parking Rate Survey, available at: Colliers International Parking Rate Survey instead: http://www.colliers.com/content/globalcolliersparkingratesurvey2009.pdf
Default TRIMMS trip lengths used where trip length was not available by mode
Where FY trip lengths and auto operating costs not provided, these were assumed same as BY
Data not provided by MPOs are marked by "-"
(1) Used TRIMMS default public transit trip length of 12.2 where no data was provided by the MPO
(2) Used TRIMMS default cycling trip length of 2.9 where no data was provided by the MPO
(3) Used TRIMMS default walking trip length of 0.9 where no data was provided by the MPO
(4) Used TRIMMS default Other trip length of 12.2 where no data was provided by the MPO; for Salt lake City, Rochester, Raleigh-Durham and Wilmington, used auto drive alone trip length for "other" mode since TRIMMS default appeared too high for these cities
(5) In many cases, walk and bike travel times were not available; therefore, for consistency across cities, data from the American Community Survey 2005-2007 were used, available at: http://ctpp.transportation.org/profiles_2005-2007/ctpp_profiles.html. Since this source groups walk, bike, and other modes into the category "other", no separate travel times are given for walk and bike and the travel times listed above under "other" can be considered average across these modes

Table A-9. National Emissions Reductions				
	Actual (grams per day)		Percentage	
	2030	2050	2030	2050
1	**Region-wide TDM**			
NO_x	1,158,438	3,764,014	0.10%	0.26%
VOC	739,609	2,562,147	0.09%	0.25%
$PM_{2.5}$	101,349	360,877	0.10%	0.26%
CO_2 equivalent	2,914,224,009	10,472,471,706	0.10%	0.26%
2	**Land use changes + TDM**			
NO_x	12,084,721	42,656,208	1.00%	2.93%
VOC	7,837,082	2,562,147	0.98%	2.86%
$PM_{2.5}$	1,051,190	360,877	1.01%	2.96%
CO_2 equivalent	30,177,541,913	117,765,791,643	1.01%	2.97%
3	**Land use changes + Transit fare reduction + TDM**			
NO_x	16,762,872	60,434,817	1.39%	4.16%
VOC	10,934,000	42,166,321	1.36%	4.08%
$PM_{2.5}$	1,454,970	5,743,848	1.40%	4.18%
CO_2 equivalent	41,743,724,738	166,274,160,854	1.40%	4.19%
4	**Land use changes + Transit fare reduction + Transit service improvements + TDM**			
NO_x	17,324,704	62,197,472	1.43%	4.28%
VOC	11,344,808	43,717,356	1.41%	4.23%
$PM_{2.5}$	1,501,521	5,895,642	1.44%	4.29%
CO_2 equivalent	43,061,338,160	170,539,394,836	1.44%	4.30%
5	**Land use changes + Transit fare reduction + Transit service improvements + Parking Fees + TDM**			
NO_x	35,232,500	99,977,456	2.91%	6.87%
VOC	23,248,699	69,056,024	2.90%	6.68%
$PM_{2.5}$	3,044,728	9,536,337	2.92%	6.94%
CO_2 equivalent	87,246,215,207	276,828,363,309	2.92%	6.98%
6	**Land use changes + Transit fare reduction + Transit service improvements + Mileage Fees + TDM**			
NO_x	23,161,418	89,739,448	1.92%	6.17%
VOC	15,026,958	61,482,738	1.87%	5.95%
$PM_{2.5}$	2,014,373	8,584,360	1.93%	6.25%
CO_2 equivalent	57,825,922,017	249,185,850,704	1.94%	6.28%
7	**Land use changes + Transit fare reduction + Transit service improvements + Parking Fees + Mileage Fees + TDM**			
NO_x	41,063,105	125,781,137	3.40%	8.65%
VOC	26,869,067	85,645,173	3.35%	8.29%
$PM_{2.5}$	3,559,935	12,058,051	3.42%	8.78%
CO_2 equivalent	102,101,807,189	350,512,043,690	3.42%	8.83%
CO_2 equivalent = [CO_2 + 21(CH_4) + 310*(N_2)]*				

Figure A-1. VMT Reduction for Each Scenario for Cluster 1 Regions



Scenarios:
1- Region-wide TDM
2 - TDM + land use changes
3 - TDM + land use changes + transit fare reduction
4 - TDM + land use changes + transit fare reduction + transit service improvements
5 - TDM + land use changes + transit fare reduction + transit service improvements + parking fees
6 - TDM + land use changes + transit fare reduction + transit service improvements + mileage fees
7 - TDM + land use changes + transit fare reduction + transit service improvements + parking fees + mileage fees

Figure A-2. VMT Reduction for Each Scenario for Cluster 2 Regions

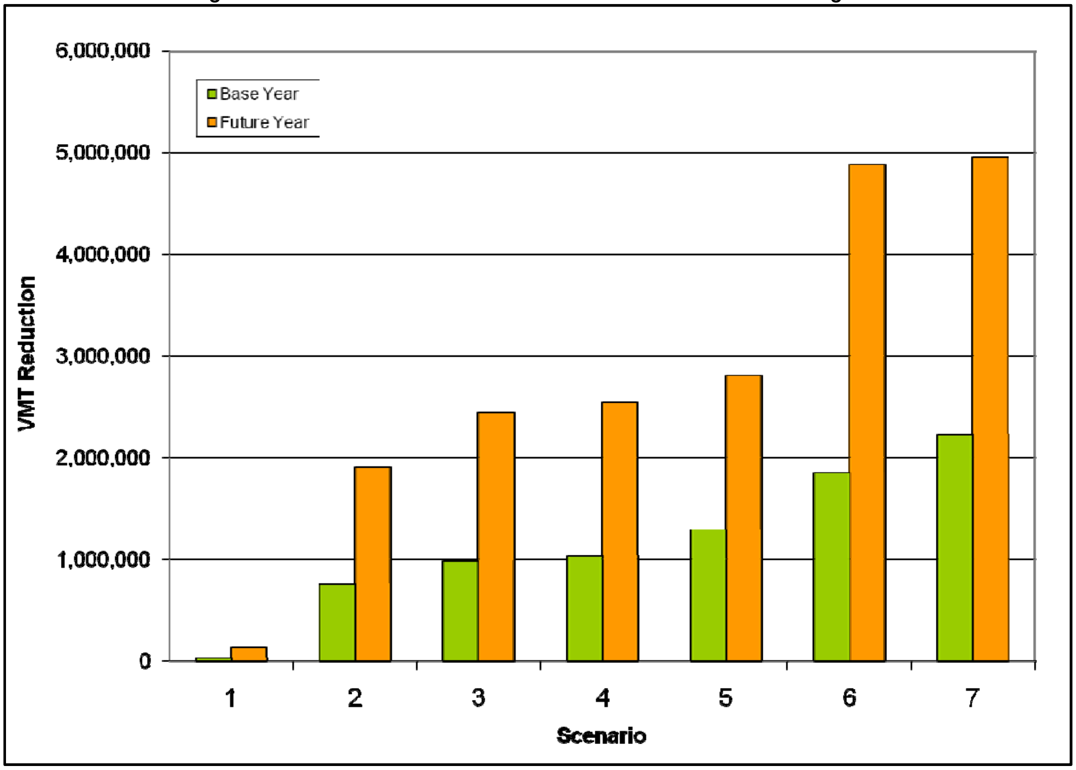


Figure A-3. VMT Reduction for Each Scenario for Cluster 3 Regions

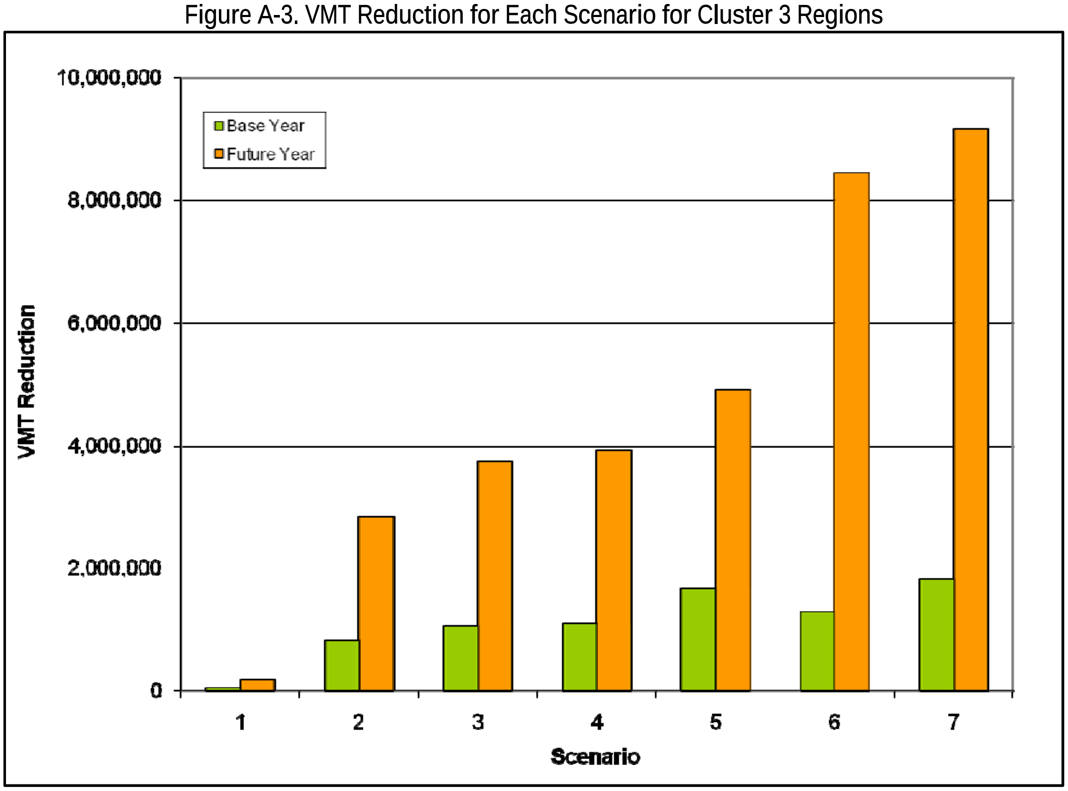


Figure A-4. VMT Reduction for Each Scenario for Cluster 4 Regions

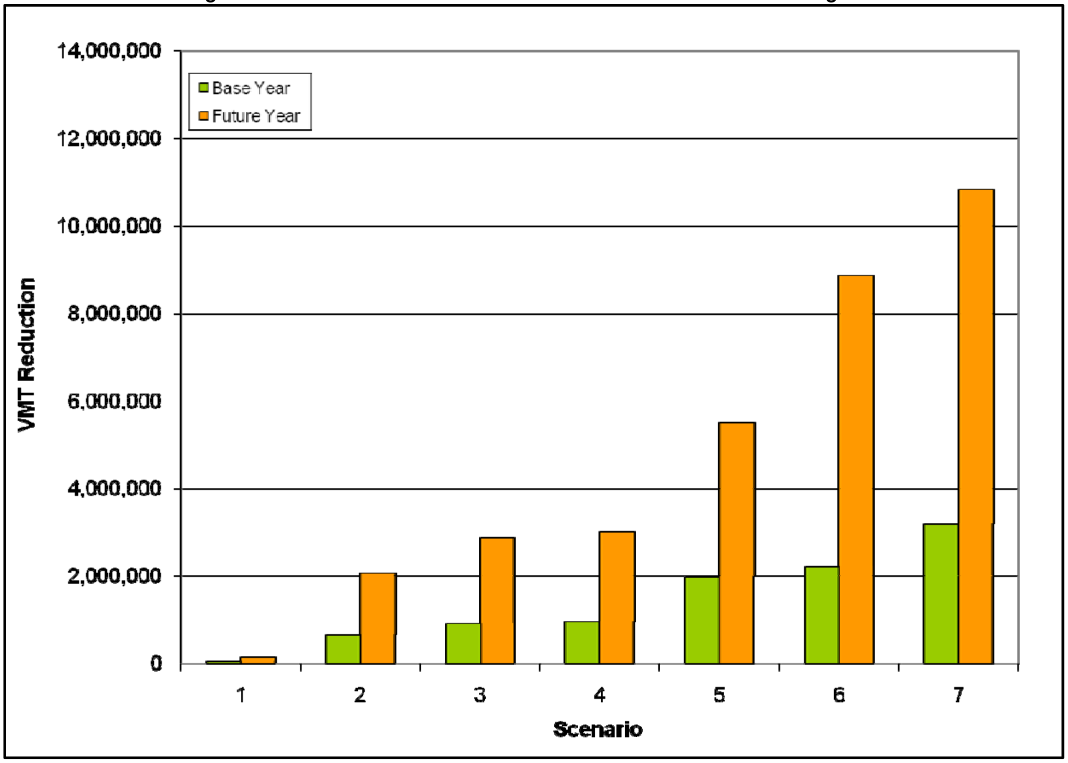


Figure A-5. VMT Reduction for Each Scenario for Cluster 5 Regions

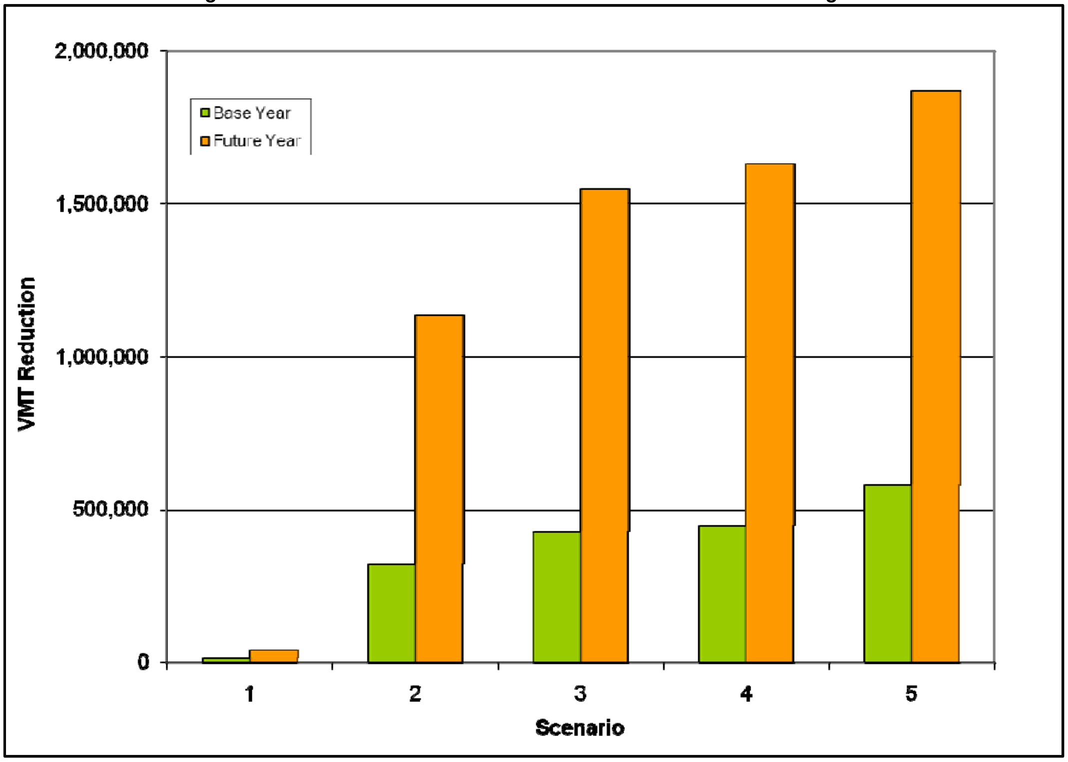


Figure A-6. VMT Reduction for Each Scenario for Cluster 6 Regions

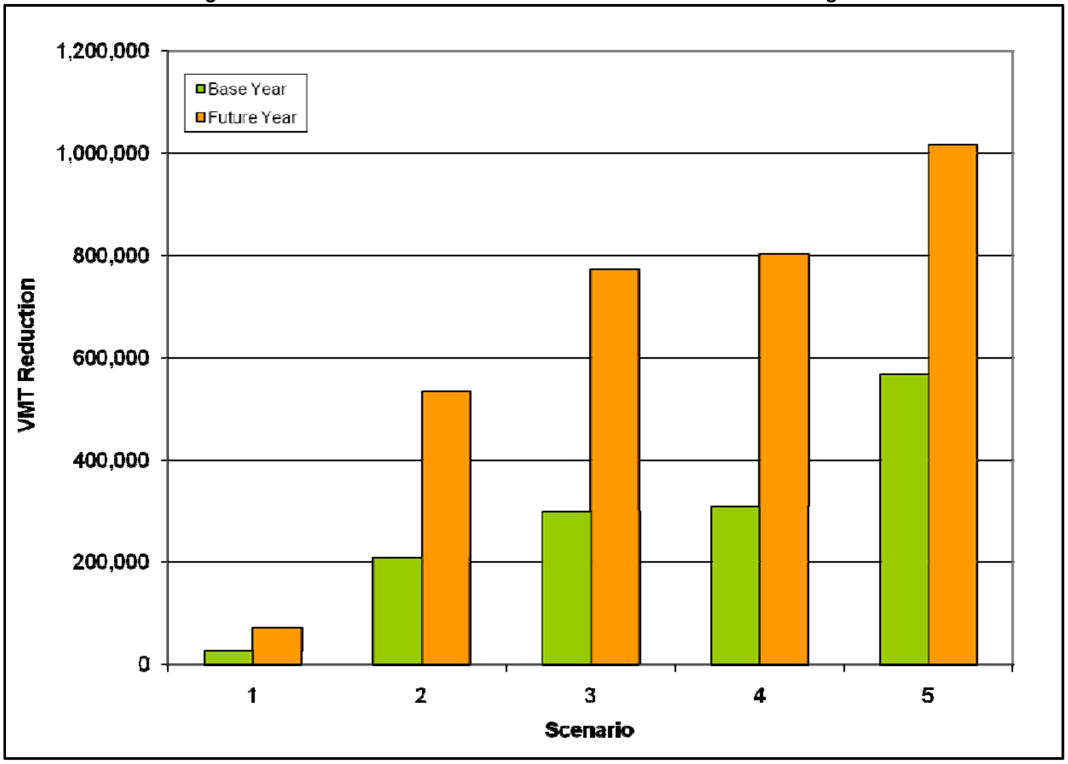
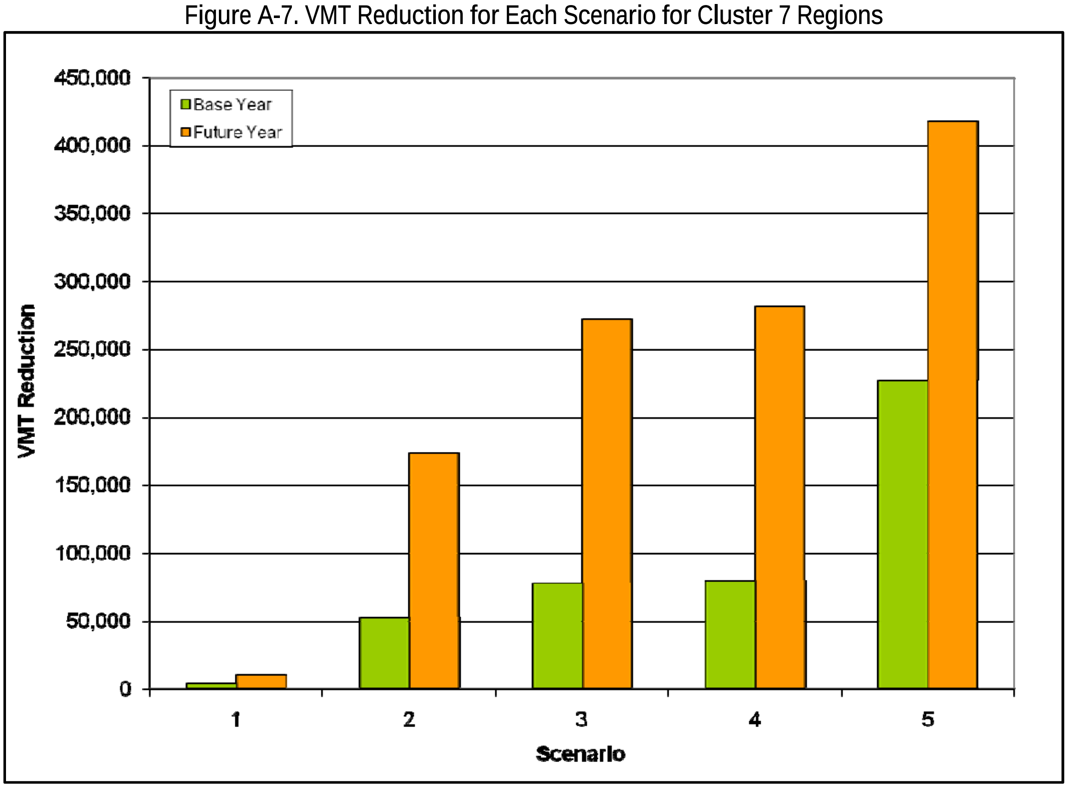


Figure A-7. VMT Reduction for Each Scenario for Cluster 7 Regions



Appendix B

Survey Data Collection Form for Analysis of VMT Impacts from Transportation Control Measures

INTRODUCTION TO THE STUDY

ICF International is conducting a study for the US EPA Office of Transportation and Air Quality to determine potential reduction in emissions from criteria, precursor, and Greenhouse Gas pollutants based on a reduction in VMT. For the purposes of this study, reduction in VMT is in response to the use of Transportation Control Measures (TCM) and other strategies that may be implemented in order to reduce the use of single occupancy vehicles. Your region has been asked to participate in this effort to serve as a representative of other regions of similar size and transit use. The analysis completed within this project will allow an estimation of reduction in VMT at the regional level that can be aggregated up to the national level for corresponding emissions reduction.

A sketch planning model will be used to develop estimated VMT reductions using data from the regional travel demand model used to support long range transportation planning. Because your region serves as a surrogate for many other similar regions, only general model data will be required. The base case will be developed from the available existing condition data and the future year will be represented by the most recently adopted plan. "Baseline information" refers to model data which does not include any specific strategies beyond the addition of infrastructure. Any insights or information that you can provide from regional analysis of TCM strategies will support a greater understanding of the results of our analysis.

We greatly appreciate your willingness to assist in this effort. The survey has been developed through interaction with MPO staff and others in order to most clearly convey the information needed. Please respond to as many of the individual questions as possible; however, where the requested information is not available, simply respond NA. If you need additional information or clarification in order to respond, our staff is available via email or phone to provide support. We hope that this participation will result in lessons learned that you will also find informative and useful. At the end of the project, we will communicate the results to the entire group of participants.

SECTION I.

Baseline MPO Data

Background Information

Names of cities/towns/entire counties included in region under MPO jurisdiction ____________________

Total population in modeled area ____________________

Total working population (16 and over) in modeled area ________________

What is the base year for your travel demand model? __________________________

[The base year is the existing year for current planning in the modeled area].

What is the future/horizon year for your travel demand model? _________________________

[The future year is the year of your adopted long range plan for the modeled area; e.g. 2035.].

Can you provide data for any intermediate years between your base year and future year? Intermediate years may be any of those years considered in the air quality conformity process. ____________________________

Please provide the following information about all trips made using light duty vehicles in your region for your model base year, future/horizon year, and any intermediate years considered. Please do not include commercial vehicle trips. If data are not available, please leave cells blank.

Note that the data we are looking for must be drawn from your travel model related to long range planning in your region. If you have additional reports or sources for observed data through surveys, etc. please provide the references or web links separately. These will help inform our analysis. Instructions for each individual subsection are provided below.

1) Current mode share (%)

In our analysis, mode share is defined as the percentage of population traveling by each mode, i.e. person-trips rather than vehicle-trips. If mode shares are not available for all modes, please leave corresponding cells blank. The total of all mode shares you provide **must equal 100%.** In the table below, please provide baseline information for your future year, and an intermediate year for which you may have data. Base case information for each year includes data on regional light duty trips *assuming all existing and committed infrastructure in place and your projections of population, jobs, and housing*, but no future policy scenarios or strategies. Details about scenarios or strategies that have been proposed and modeled in your region will be required in Section II of this questionnaire.

If you are entering data for combined modes (e.g. Walking + Cycling, Auto-rideshare + Vanpool), please fill in the value in a relevant row above and provide a brief explanation in Comments. Use the same definitions of modes you enter here for the rest of the data items in this section.

Mode share (%)	**Base year**	**Future year -- base case**	**Intermediate year -- base case**
Auto-drive alone			
Auto-rideshare			
Vanpool			
Public transit			
Cycling			
Walking			
Other			

Please specify the modes you have provided data for in the "Other" field ____________________________

Comments: ____

____

2) Average Trip Length (Miles)

In the table below, please provide baseline information for your future year, and an intermediate year for which you may have data. If average trip lengths are not available for all modes, please leave corresponding cells blank.

Average Trip Length (miles)	Base year	Future year -- base case	Intermediate year -- base case
Auto-drive alone			
Auto-rideshare			
Vanpool			
Public transit			
Cycling			
Walking			
Other			

3) Average Trip Travel Time (Minutes)

In the table below, please provide baseline information for your future year, and an intermediate year for which you may have data. If peak and off-peak data are not available, please enter the average values for the modes applicable. If average travel times are not available for some modes, leave corresponding cells blank.

Average Travel Time (Minutes)	Base year			Future year			Intermediate year		
	Peak	*Off-peak*	*Average*	*Peak*	*Off-peak*	*Average*	*Peak*	*Off-peak*	*Average*
Auto-drive alone									
Auto-rideshare									
Vanpool									
Public transit									
Cycling									
Walking									
Other									

4) Average Vehicle Occupancy (Number of persons)

In the table below, please provide baseline information for your model base year, horizon year, and any intermediate years for which you have data. If peak and off-peak data are not available, please enter the average values for the modes applicable. If vehicle occupancy numbers are not available for some modes, leave corresponding cells blank.

Avg. Vehicle Occupancy (persons)	Base year			Future year			Intermediate year		
	Peak	*Off-peak*	*Average*	*Peak*	*Off-peak*	*Average*	*Peak*	*Off-peak*	*Average*
Auto-rideshare									
Vanpool									
Bus									

5) Peak and Off-peak Trips

Please state which hours you define as AM peak, PM peak, and off-peak

AM: -----------------------------------

PM: -----------------------------------

Off-peak: ----------------------------

	Base year	Future year -- base case	Intermediate year -- base case
Percentage of total trips in peak hours (%)			
Total trips in peak hours			
Total trips in off-peak hours			

6) Trip and Parking Costs

Please enter the current passenger trip costs by mode in your region. Trip costs do not include parking costs or other costs such as tolls, fees, and peak hour charges. *If trip costs are not available, go to Section 7 to enter data from which these can be estimated.*

Trip Costs (Current $ per trip)

Average Trip Costs	Base year	Future year -- base case	Intermediate year -- base case
Auto-drive alone			
Auto-rideshare			
Vanpool costs			
Public transit fare			
Cycling			
Other			

Automobile Parking Costs (Current $ per auto per day)

Average Parking Costs	Base year	Future year -- base case	Intermediate year -- base case
Auto-drive alone			
Auto-rideshare			

Other Auto Trip Costs not included in Parking Costs, e.g., tolls, peak hour fees, etc.

(Current $ per trip)

Average Parking Costs	Base year	Future year -- base case	Intermediate year -- base case
Auto-drive alone			
Auto-rideshare			

Check the cost categories below that your model uses to calculate trip costs and briefly state the assumptions used for future years

✓	Cost categories	Assumptions for future years
	Fuel	
	Insurance	
	Maintenance/repairs	
	Ownership costs, i.e. vehicle costs, registration and licensing fees	
	Other; please specify ______________________	

7) Vehicle Mileage data to Calculate Operating Costs

Average Mileage (Miles Per Gallon)	Base year	Future year -- base case	Intermediate year -- base case
Automobiles			
Vans			
Bus			

8) Detailed Trip Travel time Information

If access times and in-vehicle travel times are not available separately, please leave cells blanks. Average travel times by mode will be assumed from the values you entered in part 3 above.

Trip Travel Time (Minutes)	Base year		Future year		Intermediate year	
	Access time	*Travel time*	*Access time*	*Travel time*	*Access time*	*Travel time*
Auto-drive alone						
Auto-rideshare						
Vanpool						
Public transit						
Cycling						
Walking						
Other						

SECTION II.

Strategies Modeled by MPOs and Assumptions for Future Years

Assumptions for regional policies and investments: Check below which strategies have been included in your base year, future year, and intermediate year. Add rows to add additional key scenarios comprising more than one strategy

Policy Assumptions	Base year	Future year	Intermediate year
Transit infrastructure or service improvements **[1]**			
Higher auto parking charges **[2]**			
Congestion fees, tolls or toll increases for autos **[3]**			
Land use strategies (TOD, mixed use, higher density) **[4]**			
Employer-initiated TDM policies and incentives **[5]**			
Other policies or investments not mentioned **[specify, e.g. HOV lanes, bike/ped. Incentives, roadway improvements]**			
Package comprising more than one of these strategies **[specify, e.g. 1+2, 2+3+4, etc.]**			

Please enter below the data results from your own modeling studies on the estimated impacts of the above scenarios.

Mode Share Changes Resulting from Packages of Measures You Have Modeled in Your Region

Modeled packages of strategies	**Package 1**	**Package 2**	**Package 3**	**Package 4**	**Package 5**
Future year considered					
Strategy assumptions (e.g. reduction in transit travel time of X%, reduction in auto trip lengths by Y%, increase in auto driving costs by Z%, etc.)					
MODEL OUTCOMES					
New Mode Shares (%)					
Auto-drive alone					
Auto-rideshare					
Vanpool					
Public transit					
Cycling					
Walking					
Other					

If you have modeled the following strategies individually, and not in combined scenarios, please provide your estimates of impacts in the tables below.

(1) Increase in Driving Costs

(2) Change in Transit Fares

(3) Change in Transit Access or Travel Time

(4) Change in Auto Travel Time

In the top section of each table, provide the values that you assumed or that were calculated through your models, and the mode shares reflecting these changes. All results you record below should be relative to the base case scenario for each year.

Note: if you did not model the strategies below individually but only as part of packages of strategies, please enter the estimates of resulting mode share changes in the table above.

Mode Share Changes Resulting from Increase in Driving Costs (higher tolls, parking, or congestion charges)

Modeled change in pricing policy	Base year	Future year	Intermediate year
% change in parking cost			
% change in tolls, congestion fee			
% change in fuel price assumed			
MODEL OUTCOMES			
New Mode Shares (%)			
Auto-drive alone			
Auto-rideshare			
Vanpool			
Public transit			
Cycling			
Walking			
Other			

Mode Share Changes Resulting from Change in Transit Fares

Modeled change in pricing policy	Base year	Future year	Intermediate year
% change in transit fares			
MODEL OUTCOMES			
New Mode Shares (%)			
Auto-drive alone			
Auto-rideshare			
Vanpool			
Public transit			
Cycling			
Walking			
Other			

Mode Share Changes Resulting from Change in Transit Access or Travel Time

Modeled change in pricing policy	**Base year**	**Future year**	**Intermediate year**
% change in transit access time			
% change in transit travel time			
MODEL OUTCOMES			
New Mode Shares (%)			
Auto-drive alone			
Auto-rideshare			
Vanpool			
Public transit			
Cycling			
Walking			
Other			

Mode Share Changes Resulting from Change in Auto Travel Time

Modeled change in pricing policy	**Base year**	**Future year**	**Intermediate year**
% change in auto travel time			
MODEL OUTCOMES			
New Mode Shares (%)			
Auto-drive alone			
Auto-rideshare			
Vanpool			
Public transit			
Cycling			
Walking			
Other			

If you would like to provide any comments about VMT and emissions reduction strategies/scenarios you have considered in your region, please enter them here.

Please list the tool(s) you used to conduct your analyses along with a brief description:

SECTION III

Elasticity Values Assumed for Sensitivity to Trip Costs and Travel Times

Demand elasticity is defined as the percentage change in the use of a particular transportation mode resulting from a 1% change in an attribute such as price, travel time, or frequency of service offerings. Elasticity values should be entered with a positive sign or a negative sign. Please enter transportation price elasticities by mode, trip purpose and time of day below. If these values are not available by trip purpose or for peak/off-peak hours, simply provide average elasticity values. *Please fill in as much information as you can, even if it is incomplete. If you have studies or surveys for your region that we can use to estimate these values, please email them to us with your responses to this survey.*

Elasticity with respect to Parking/Driving Costs

Trip Purpose	**Modes**			
	Auto	Rideshare	Public transit	Other
Commuting				
Business				
Education				
Other				

Transit Elasticities: In the table below, please provide elasticities of transit ridership

	Peak	**Off-Peak**	**Average**
Transit Ridership with respect to Transit Fare			
Transit Ridership with respect to Transit Service			
Transit Ridership with respect to Auto Operating Costs			
Auto travel with respect to Transit Costs			

Travel Time Elasticities

	Peak	**Off-Peak**	**Average**
Auto			
Rideshare			
Public transit			

If cross-elasticities across modes are available please provide these in the table below, otherwise move on to Section III.

		Auto	Rideshare	Public transit
Peak	Auto			
	Rideshare			
	Public transit			
		Auto	Rideshare	Public transit
Off-peak	Auto			
	Rideshare			
	Public transit			
		Auto	Rideshare	Public transit
Average	Auto			
	Rideshare			
	Public transit			

THANK YOU VERY MUCH FOR YOUR TIME.

YOUR PARTICIPATION IS GREATLY APPRECIATED

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