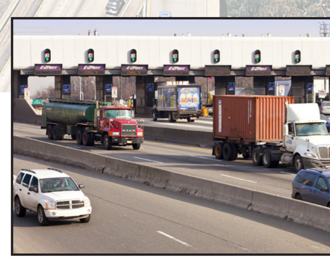
Estimating Emission Reductions from Travel Efficiency Strategies:

Three Sketch Modeling Case Studies



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Transportation and Climate Division
Office of Transportation and Air Quality
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Executive Summary

Background

The purpose of this report is to document how the "Travel Efficiency Assessment Method" previously used for a national assessment could be applied to specific regions to estimate the reductions in vehicle miles traveled (VMT), greenhouse gas (GHG) emissions, and criteria pollutant emissions. The U.S. Environmental Protection Agency (EPA) collaborated with state and local government officials in three regions to complete these case studies: Pima County Association of Governments (PAG) for the Tucson, AZ region, Massachusetts Department of Transportation (MassDOT) for the Boston, MA region, and Mid-America Regional Council (MARC), for the Kansas City, MO Region. EPA offered technical assistance and the collaborating agencies offered their time, expertise, and local data to assess reductions in greenhouse gas (GHG) and criteria emissions from a set of travel efficiency strategies selected by and tailored to each particular region.

Travel efficiency strategies represent the broad range of strategies designed to reduce travel activity, especially single-occupancy travel. The term "travel efficiency strategies" builds on the traditional Transportation Control Measures (TCMs) listed in Section 108(f)(1)(A) of the Clean Air Act (CAA) such as provision of transit, high-occupancy vehicle (HOV) lanes, and park and ride lots, and includes other strategies such as transportation pricing such as parking pricing and per-mile pricing and smart growth, such as transit-oriented development.

These case studies build on other EPA research to quantify the potential reductions in transportation-related emissions resulting from travel efficiency strategies that reduce VMT. EPA developed a methodology to estimate VMT and emissions reduced from travel efficiency strategies called the **T**ravel **E**fficiency **A**ssessment **M**ethod (**TEAM**). TEAM uses available travel data and a sketch model analysis to quantify the change in VMT, combined with the EPA MOVES2010 (Motor Vehicle Emission Simulator) model's emission factors to estimate the emission reductions that can reasonably be expected. The method allows evaluation and comparison of scenarios, and thus provides a useful tool for state and local planners who want to assess impacts of possible strategies before adopting them. This method was applied to urban areas nationwide to estimate the potential impact that adopting travel efficiency strategies could have, and the results were documented in EPA's recent study, *Potential Changes in Emissions Due to Improvements in Travel Efficiency*[1] *(2010 national study)*.

EPA had also provided a user guidance document that describes the methodology in detail, so that others interested in such an analysis could follow the method established. In 2011, EPA issued the guidebook describing the TEAM approach titled, *Analyzing Emission Reductions from Travel Efficiency Strategies: A Guide to the TEAM Approach.*[2] The guide describes the TEAM approach to estimating the emission reductions from travel efficiencies at the regional

[1] 2010 national study, www.epa.gov/otaq/stateresources/policy/420r11003.pdf

[2] User Guidance for TEAM, http://www.epa.gov/otaq/stateresources/policy/420r11025.pdf

level using information that is typically available from a travel demand model. The analysis can also be conducted for smaller geographical areas to the extent that the areas are covered by a travel demand model and the data for these areas can be extracted from the model. The guide describes the information and data required for analysis, step-by-step procedures for performing the analysis, considerations for making assumptions about the strategies of interest, and considerations for interpreting the results. In addition, it identifies default values, alternative sources of information, and data that can be used when local data and information is incomplete or absent.

EPA began these case studies in 2012, by requesting letters from agencies interested in applying TEAM in their local region to evaluate their own selected travel efficiency strategies. From those that applied with a letter of interest, three agencies were selected as case studies for testing the TEAM approach at a regional level: Pima County Association of Governments (PAG) for the Tucson, AZ region, Massachusetts Department of Transportation (MassDOT) for the Boston, MA region, and Mid-America Regional Council (MARC), for the Kansas City, MO Region. The selection of these participants to apply TEAM in a regional analysis provides a collaborative opportunity to determine its applicability across a range of geographic, developmental and travel activity contexts. These lead agencies identified stakeholder groups to support their strategy selection and data collection. For purposes of analysis, each region's selected strategies were grouped into four scenarios. Both the strategies and their underlying assumptions represent a broad range of potential scenarios for evaluation of corresponding emissions reductions.

The results of these regional studies were compared with the results of the 2010 national study to see if they were of similar magnitude. The aforementioned Guide to the TEAM Approach recommended this validation approach, and the current study provides an opportunity for comparison. In most cases, the comparison validated that individual agency results were reasonable. This 2013 regional study estimates fewer potential emissions reduction in response to the scenarios selected by the regions, especially in regard to land-use strategies. Because of this, the 2013 regional study highlights some important lessons learned that can inform future applications of the TEAM approach.

Analysis and Results

Selected Strategies

The three regions selected travel efficiency strategies for modeling that fall into four categories: Travel Demand Management (TDM) or Employer Incentives, Transit, Land Use, and Pricing. PAG defined its scenarios as four separate strategies with no overlap, while the other two case study regions applied their strategies to achieve a progressive increase in VMT reduction across scenarios. Table 1 provides a brief description of each region's selected strategies.

Table 1. Regional Scenario Descriptions

Scenario	Description
PAG	
Scenario 1: SunTran All Access Pass	Provides an unlimited-ride transit pass for almost 90,000 faculty, staff, and students at the University of Arizona and Pima Community College
Scenario 2: Expanded Employer-based Incentives	Increases subsidies for those currently eligible for commute subsidies
Scenario 3: Bus RapidTransit (BRT) on 2 Corridors	BRT on two major corridors in the region that bring traffic into and out of downtown
Scenario 4: Parking Pricing in Downtown	Doubles parking prices in a specific downtown-university area along with expanding the share of parking that is priced
EPA Scenario: Land Use changes with all other scenarios	Concentrates population growth in existing urban centers
MassDOT	
Scenario 1: Expanded Healthy Modes Program	Increase the number of employees with access to MassRIDES by 25% and expand access to employer-paid monetary subsidies to all employees with access to MassRIDES
Scenario 2: Scenario 1 + Land Use	Adds Smart Growth Land Use to Scenario 1 with an increased emphasis on growth in existing urban centers
Scenario 3: Scenario 2 + HOV Lanes	Adds HOV to Scenario 2 with a decrease in rideshare travel time for the entire region based on a network of HOV lanes
Scenario 4: Scenario 3 + Expanded Transit	Adds transit network expansion and improvement to Scenario 3 to reduce both transit trip times and access times (wait times) for the regional population
MARC	
Scenario 1: Expanded TDM	Expands the group with access to telework and flexwork programs and adds alternative mode subsidies for this expanded group
Scenario 2: Scenario 1 + Enhanced Transit	Adds transit improvement and promotion to Scenario 1 by reducing transit trip times, reducing walking distance to transit, and expanding the University's successful transit pass program
Scenario 3: Scenario 2 + Land Use	Adds Smart Growth Land Use to Scenario 2 to increase average residential density and mixed land uses for the entire regional population
Scenario 4: Scenario 3 + Pricing	Adds transportation pricing to Scenario 3 as an increase in the average cost of auto trips and increase parking costs in the Downtown Area

An important element of this study was to evaluate how changes in land use, particularly the implementation of smart growth principles, support emissions reductions. Given the long lead times needed for cities to implement smart growth development plans, EPA chose a thirty year time horizon to model the results of the different scenarios.

Both MassDOT and MARC included a land use strategy; however, PAG chose not to test the effectiveness of a land use strategy. To provide a balanced comparison across regions and a point of comparison with the previous national study, a reasonable land use strategy was independently developed by EPA for the PAG region. The results are included as an additional scenario that uses land use as a foundation for the other strategies requested by PAG.

After conducting a review of various sketch planning models in EPA's 2010 national study, the TRIMMS model developed by the Center for Urban Transportation Research (CUTR)[3] was selected to demonstrate the TEAM approach. Several factors recommend using TRIMMS for this type of analysis, including the type and format of inputs required, the geographic scale of analysis, and the capability of modeling a variety of TCMs, making it highly useful for this type of analysis.

MOVES2010b was used to determine appropriate emission factors for all regions. MOVES was run in inventory mode to produce activity-weighted average emission factors. Four primary pollutants were considered in this analysis: CO_2-Equivalent, NOx, $PM_{2.5}$, and VOC.

Results and Lessons Learned

While estimates of VMT and emission reductions from each case study region are generally within the range of results for similar regions in the 2010 national study, they are not directly comparable to the 2010 national study, or to each other. The differences observed can be attributed to the underlying assumptions and the affected population for each region and the scenarios selected to be modeled. For example, in one of the cases, a strategy was applied to a limited set of corridors rather than to all roads; in a couple of the cases, strategies were applied to a subset of the population rather than to the entire population. The scenarios were tailored to each region and based on the agencies' individual goals for the case study. The regions were diverse in their selection of strategies, as well as availability, type and completeness of data for the models. This limits their comparability to each other, and to the 2010 national study. However, focusing on specific regions in this way was the one of the reasons for pursuing case studies. In addition, the differences in the regions provided more insight to the strengths and challenges of the analytical tools used.

To expand on that point, each of the regions had a different future "business as usual" (BAU) scenario that was used as the benchmark to compare that region's scenarios of travel efficiency strategies. The BAU scenario was unique to each region and reflected what is already planned in that area for the future. Each region made a decision for what to include in their BAU. In Boston, the MPO developed two land use forecasts, one the continues recent historical development and one that concentrates future growth in core areas served by transit. The BAU in the Boston case study included the latter. With this in mind, the differences between the BAU and the other scenarios modeled in the Boston region is smaller than it would have been if the BAU scenario reflected the more dispersed land use patterns of the recent past. In the Kansas City region, the MPO created three land use forecasts: one that continues current trends, one that focuses growth in core areas, and a compromise between these two that was adopted by the MPO board. In contrast to Boston, in the Kansas City case study the BAU scenario included

[3] Concas, S. and P.L. Winters; Economics of Transportation Demand Management (TDM), 2007, "Estimating Costs and Benefits of Emission Reduction Strategies for Transit by Extending the TRIMMS model." 2012, and Quantifying the Net Social Benefits of Vehicle Trip Reductions: Guidance for Customizing the TRIMMS Model, 2009;National Center for Transit Research at the Center for Urban Transportation Research: Tampa

the current trends forecast rather than the focused growth forecast or the adopted compromise. The fact that each region had a unique BAU scenario is one reason why results from one region are not directly comparable to another. The results illustrate the flexibility of the method, with this particular version of the sketch model used.

Agencies wanting to model more aggressive policies, applied to broader populations, showed larger emission reductions. As in the national-level analysis, pricing strategies outperform the others when applied to a significant share of the population. The largest reductions result from a combination of mutually supportive strategies modeled together, compared to the sum of individual strategies modeled separately. For example, land use, transit and TDM improvements can be mutually supportive and produce better results than when considered individually. The scale of implementation of a strategy can have important implications for the results as well. When the population or geography is reduced to a subset of the region, the benefits may be large to the affected population, but quite small for the region as a whole.

VMT and emission reductions for each of the future year scenarios, expressed as a percent change, as compared to the business as usual baseline, are provided in Table 2.

Table 2. Percent VMT and Emissions Changes

Percent Emissions Changes for Selected Pollutants 2040 BAU compared to 2040 Scenario					
Scenario	Light-Duty VMT	GHGs (CO_2 equivalent)	PM2.5	NOx	VOC
PAG					
Scenario 1: SunTran All Access Pass	-0.99%	-0.97%	-0.94%	-0.86%	-0.77%
Scenario 2: Expanded Employer-based Incentives	-0.43%	-0.43%	-0.42%	-0.40%	-0.44%
Scenario 3: BRT on 2 Corridors	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%
Scenario 4: Parking Pricing in Downtown	-0.26%	-0.25%	-0.25%	-0.24%	-0.26%
EPA Scenario: Land Use changes with all other scenarios	-1.95%	-1.87%	-1.73%	-1.43%	-0.71%
MassDOT					
Scenario 1: Expanded Healthy Modes Program	-2.80%	-2.80%	-2.80%	-2.79%	-2.77%
Scenario 2: Scenario 1 + Land Use	-3.88%	-3.89%	-3.88%	-3.88%	-3.84%
Scenario 3: Scenario 2 + HOV Lanes	-4.06%	-4.06%	-4.06%	-4.05%	-4.02%
Scenario 4: Scenario 3 + Expanded Transit	-4.40%	-4.41%	-4.40%	-4.39%	-4.36%
MARC					
Scenario 1: Expanded TDM	-0.93%	-0.93%	-0.93%	-0.92%	-0.92%
Scenario 2: Scenario 1 + Enhanced Transit	-2.35%	-2.35%	-2.35%	-2.35%	-2.34%
Scenario 3: Scenario 2 + Land Use	-2.49%	-2.49%	-2.49%	-2.48%	-2.48%
Scenario 4: Scenario 3 + Pricing	-12.05%	-12.05%	-12.05%	-12.03%	-12.02%

Data

Regions that undertake a TEAM analysis should allow for a significant amount of preparation time to identify data requirements, collect or identify substitute data elements and validate the appropriateness of the data for this type of analysis. TEAM was developed to use regional planning data without requiring significant additional data collection or extensive re-evaluation of the information. Data validation to determine the appropriateness for analysis is an essential step in the TEAM approach. This study found that the reasonableness of data in common use shouldn't be taken for granted. For instance, the distribution of VMT for transit vehicles among road types is unlikely to be the same as for passenger cars. Road type has an impact on vehicle speeds, and thus can have a significant impact on emissions. A critical element for applying TEAM successfully is the ability to identify questionable data and develop substitutions when needed.

Analysis Tools

The analysis demonstrated that TRIMMS can be an effective sketch modeling tool to estimate VMT reductions from a variety of travel efficiency strategies. Many of the model's functions work by manipulation of travel times and travel costs, common factors used in travel demand modeling. While TRIMMS can provide a relatively rapid and low cost evaluation of travel efficiency strategies, more comprehensive land-use and transportation modeling should be used to confirm the analysis before making final policy decisions. The analysis also raised questions about the estimated impacts of higher density land use. TRIMMS land use analysis features are in an early stage of development, and the results appear to underestimate impacts on VMT and are inconsistent with current literature. The web-based version currently under development is intended to improve the land use capabilities.

MOVES is EPA's on-road mobile source emissions model, and is required to be used for regulatory purposes under the Clean Air Act. Specifically, MOVES is required to be used for estimating on-road emissions in State Implementation Plans (SIP) and transportation conformity determinations. This project has shown that some regions are becoming increasingly familiar with its use. Accordingly, many are developing their own local MOVES input data to make the analyses more sensitive to local transportation characteristics. If local inputs were available, they were employed for the TEAM analysis and where unavailable, MOVES default data was used. For this non-regulatory planning purpose, the MOVES default data inputs were sufficient to compare and contrast different scenarios. TEAM analyses and CAA regulatory analyses may rely on some common data, but TEAM cannot be used to perform the regulatory analyses required by the CAA.

For each of the regions, MOVES was used to estimate average emissions per mile and per start, and these rates were applied to the resulting change in VMT and trips to calculate the potential benefit of the strategies. These case studies illustrate the flexibility inherent in MOVES. EPA's MOVES guidance documents describe different methods that can be used to estimate equivalent emissions in a given area, and in each of the regions, a difference approach was used.[4] In one case, MOVES was run for the one relevant county. In another, MOVES was run for a custom domain, using inputs from one "representative" county. For the third, several counties were modeled individually and the results summed. In addition, the three areas had a variety of locally available data and relied on the default data within MOVES to varying degrees. The MOVES results in terms of per-mile and per-start rates developed in each of the three areas can be found in Tables 8, 12, and 16.

Conclusions

The foundation of the TEAM approach is the development of scenarios and translating those scenarios into reasonable input values that can be used by the TRIMMS and MOVES models. The scenarios can represent reasonably achievable goals or can be an acknowledged "reach" for a more significant change from the BAU case. A stakeholder group composed of well-informed local transportation planners, experienced modelers and land use planners can develop the scenarios and associated model inputs for a region based on their professional knowledge and limited additional research. While scenarios can be reasonably achievable in the

[4] Using MOVES to Prepare Emission Inventories in State Implementation Plans and Transportation Conformity: Technical guidance for MOVES2010, 2010a and 2010b, EPA-420-B-12-028, April 2012,

Using MOVES for Estimating State and Local Inventories of On-Road Greenhouse Gas Emissions and Energy Consumption – Final (PDF) (74 pp, 2.4M, EPA-420-B-12-068, November 2012) long term, they can also represent aggressive regional goals, unconstrained by shorter term political, fiscal, or technological challenges.

Although results for each region were compared for reasonableness to the similar representative regional clusters from the 2010 national study, in some cases it was more instructive to compare the results to the full range of results of the 2010 national study. Population size and transit mode share do not capture other regional characteristics that can affect the results, such as average trip lengths, travel costs, climate and geography. In addition, strategy assumptions, as translated into model input values, may have a significant effect on the results. Strategies can be specified in more or less aggressive inputs, and can be restricted to sub-populations and sub-geographies or a region.

The TEAM approach, utilizing travel sketch modeling, regional travel data, information from the literature, and emissions estimates from the MOVES model, produces reasonable estimates of emissions reductions from travel efficiency strategies. These case studies tested the approach in a variety of regional contexts, and the results, while more conservative, fall within the range predicted by the 2010 national study. Differences appear more related to the appropriateness of the data used and the limitations of the travel sketch model than the approach itself. The regional analysis was conducted with TRIMMS 3.0, which includes some significant changes since the previous version used for the 2010 national analysis, and may have contributed to some differing results. Given more time, regions should be able to develop better data and improve the assumptions in TRIMMS and MOVES, making TEAM a useful approach to support regional decision-making.

1. Introduction and Background

1.1. Introduction to TEAM

The U.S. Environmental Protection Agency (EPA) has a long history of supporting research to quantify the potential reductions in transportation-related emissions resulting from travel efficiency strategies that reduce vehicle miles traveled (VMT). Travel efficiency strategies represent the broad range of strategies designed to reduce travel activity, especially single-occupancy travel. The term “travel efficiency strategies” builds on the traditional Transportation Control Measures (TCMs) listed in Section 108(f)(1)(A) of the Clean Air Act (CAA) by adding other strategies such as transportation pricing and smart growth.

This report documents EPA’s latest effort to contribute to the state of the practice for assessing the impacts of travel efficiency strategies in reducing transportation emissions. The purpose of the effort was to develop a collaboration with state or local government officials to demonstrate a methodology developed by EPA and documented in the recent study, *Potential Changes in Emissions Due to Improvements in Travel Efficiency*[5] *(2010 national study)*, and to quantify potential emission reductions from travel efficiency strategies at the regional level. EPA identifies the methodology as the **T**ravel **E**fficiency **A**ssessment **M**ethod (TEAM), TEAM uses commonly available regional travel data and sketch modeling analysis to quantify changes in VMT, combined with emissions estimates from the EPA MOVES2010 (Motor Vehicle Emission Simulator) model’s emission factors to calculate the emission reductions that can reasonably be expected. In support of this effort, EPA provided two resources for demonstrating the methodology at the regional scale: (1) a user guidance document that describes the methodology in detail and (2) technical assistance to three regions interested in assessing reductions in greenhouse gas (GHG) and criteria emissions from these strategies. The process and results of this effort are discussed in this case study of the three selected regions.

1.2. 2010 National Study

The 2010 national study was intended to establish a reliable and useful source of information on the effectiveness of selected travel efficiency strategies and to quantify the potential national emission reductions that could result from those strategies. The study focused on light-duty vehicles and as such only considered gas and diesel fueled passenger cars and light duty trucks. The results represent the reduction in urban VMT and emissions that could be achieved with selected travel efficiency strategies applied to urban areas nationwide, with rural travel assumed to remain unaffected.

The study used data from 15 metropolitan regions to determine the potential for national-level emissions reductions. These regions were grouped into “clusters” based on the size of their population and the extent to which transit is used. Although the analysis is based on actual travel data and characteristics of real metropolitan areas, because of the aggregation and

[5] 2010 National Study, www.epa.gov/otaq/stateresources/policy/420r11003.pdf

averaging of data, the predicted changes to travel activity and resulting emissions from this analysis are not intended to represent the effectiveness of the strategies for any particular area.

The strategies analyzed 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, named Trip Reduction Impacts for Mobility Management Strategies (TRIMMS, version 2.0), and the data from representative metropolitan regions were used to estimate the national potential for reductions in VMT under a variety of scenarios. Emission factors obtained from EPA's MOVES2010 (Motor Vehicle Emissions Simulator) model were then used to convert VMT reductions into emissions reductions. Key aspects of the study included:

- A review of recent studies to determine the range of effectiveness of various strategies in addressing travel demand
- Development of an assessment methodology (Travel Efficiency Assessment Method, 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

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. Although not directly comparable due to differences in approach, the results of this study were similar to other studies estimating the potential reductions from travel efficiency strategies conducted in the recent past, such as *Moving Cooler* (Cambridge Systematics 2009).

1.3. 2013 Case Study Participants

EPA recruited regional partners to collaborate with on this project by soliciting letters of interest from state and local transportation and air quality planning agencies. The received letters of interest were considered based on the following key factors:

- *A demonstrated interest in GHG planning and analysis*
- *Regional population above 200,000 in the MPO or Metropolitan Statistical Area (MSA)*
- *Availability of data and staff resources to support the analysis and collaborate with EPA*

EPA targeted technical support to areas that are interested in exploring tools to conduct an analysis of transportation-related emissions more quickly and efficiently than the methods they currently use, if any. TEAM is a sketch planning approach that allows for some strategies to be analyzed at a regional or sub-regional scale without requiring the use of a sophisticated regional travel demand model. The approach can therefore be used either in regions with sophisticated analysis capabilities to prioritize strategies for further analysis, or as the primary analytical method in regions that do not have any established methodologies. EPA was particularly interested in partnering with agencies that expressed an intent to collaborate with regional and local partners such as state agencies, regional air quality boards, and environmental or natural resource agencies on GHG planning and analysis.

EPA received ten letters of interest from a variety of transportation agencies engaged in regional planning. Three agencies were selected to participate in the case studies, testing the TEAM approach at a regional level: Pima County Association of Governments (PAG), Massachusetts Department of Transportation (MassDOT), and Mid-America Regional Council (MARC). Each agency brought a unique perspective and interest to the study as identified below.

Pima Association of Governments – local commitment for GHG reduction through U.S. Mayor's Climate Protection Agreement; presence of baseline GHG emissions inventory; interest in wider range of strategies, including transit and TDM with ability to provide detailed data (rideshare program currently in effect); experience with generalized sketch planning tools like Climate and Air Pollution Planning Assistant (CAPPA), where the TEAM approach and use of TRIMMS could add value.

Massachusetts Department of Transportation – strong collaboration across the region and state; motivation due to state legislation and regional targets for GHG reduction; capacity to leverage knowledge gained through the case study across MPOs in the state as well as other Northeastern and Mid-Atlantic states through the Transportation and Climate Initiative; opportunity to compare results from TRIMMS against their own tools developed to test transit and non-motorized transportation strategies.

Mid-America Regional Council – availability of CarbonFIT model for land use and TDM analysis that can be used to compare results from TRIMMS; interest in a wide range of strategies including transit, land use, TDM; strong collaboration across multiple jurisdictions and two states and playing a leadership role on GHG reduction efforts in the region.

Each agency selected strategies of interest to their region and developed scenarios with these strategies based on individual goals for the case study. The regions were diverse in their selection of strategies, availability, type and completeness of data for the models, and this provided more insight to the strengths and challenges of the analytical tools used.

2. Methodology and Key Findings

2.1. Scenario Selection and Baselines

Agencies were asked to consider strategies for their region as identified in the 2010 national study (see Appendix A for the referenced tables 4 and 6) for inclusion in their scenarios. Selected strategies must be able to be specified to fit the capabilities of TRIMMS in order to estimate VMT reductions. This requirement limited the full range of potential strategies under consideration because some strategies cannot easily be modeled in TRIMMS. For instance, high-occupancy vehicle (HOV) lanes must be translated into travel time savings for input to TRIMMS. In each region, thought was given to how the travel efficiency strategies chosen could be reflected in TRIMMS, as explained further in Section 2.3.

Scenarios were comprised of groups of strategies, and assessed for their overall combined VMT reduction and emissions benefit. The 2010 national study combined strategies in increasingly aggressive scenarios by starting with the most basic strategies of travel demand management (TDM) and land use, and progressing to the more controversial strategies for many regions to implement, such as road pricing. This combining of strategies (through sequential application and modeling) helped identify how benefits may incrementally increase with additional actions over time. Both MassDOT and MARC elected to use a similar approach. PAG was more interested in specific strategies that were likely to garner political and public support, and therefore selected single strategies for each scenario. The specific strategies selected to comprise each scenario, along with the data needed to model them are provided for each agency in Section 3 of this report.

The TEAM results provide a comparison of potential emissions reductions from selected strategies with the potential emissions from a business as usual (BAU) scenario. The results are presented as percent reductions based on this comparison. For this reason the selected BAU baseline is a critical component of using this approach. The BAU scenario represents likely emissions based on the existing regional plan for transportation infrastructure and regional growth. The development of a BAU can be challenging, so participating agencies provided a range of BAU scenarios for use in this study. In most cases the BAU represents the future year infrastructure and travel activity without additional travel efficiency strategies. This is typically the scenario in the adopted long range transportation plan and is well suited for use with TEAM. It is essential to ensure that the scenarios analyzed for comparison match the geographic boundaries, fleet characteristics, population, and other parameters of the BAU scenario.

EPA has a strong interest in how land use changes, particularly smart growth principles, influence emissions reductions. MassDOT and MARC included land use strategies in their scenarios; however, PAG decided not to explore this strategy. To provide a balanced comparison across regions, a reasonable land use strategy for PAG was developed by EPA independent from the region's other strategies. The EPA land use strategy was then combined with the other strategies selected by the region to provide an additional scenario for PAG. The results of this analysis are discussed in Section 3 as a part of the PAG case study.

2.2. Data Collection and Validation

Data collection and validation is the most important task within any analysis approach, and TEAM is no exception. One of the advantages of TEAM is that it relies primarily on data inputs and outputs from typical travel demand models used for regional planning, without the need to actually run the travel demand model for each scenario being considered. This can save valuable time and other costs associated with performing several travel demand model analyses. The intent of TEAM is to support early decision making by providing a comparison of different strategies under consistent future conditions. Strategies that appear most effective and have the necessary public and political support can then be more rigorously analyzed for precise impacts using the travel demand model and other tools available to the region. When the data being used is consistent across these levels of analysis, it is more likely that confidence in the outcome of the scenario can be maintained.

Data collection for the analysis involved obtaining local data from the agencies to include in MOVES, processing them as necessary, completing quality assurance reviews of provided inputs and revising as needed, and filling gaps in the local data with national default data from MOVES to create a complete dataset. Locally specific data is preferred to default data, and efforts were made to obtain local data wherever possible. All three regions provided some local data that generally was used by the agencies for other analytical or planning purposes. Only PAG performed data collection unique to this analysis.

The data required for the TEAM analysis is primarily from the regional travel demand model, but not entirely. Responsibility for the analysis that supports transportation planning can vary across states and regions. This variation in responsibility may require cooperation among local agencies and stakeholders to support the data collection and scenario development necessary to undertake the TEAM analysis. The EPA notice for letters of interest explicitly stated that "*EPA would prefer to engage with agencies that collaborate with regional and local partners such as state agencies, regional air quality boards, and environmental or natural resource agencies on GHG planning and analysis.*"

Obtaining the data for this study included stakeholder participation in the PAG and MassDOT regions. The degree to which stakeholders were involved had a significant impact on the amount of effort required of the lead agency. MassDOT was the region with the broadest array of stakeholders, which allowed the agency to spread the data requirements and reduce the demand on lead agency staff. The region with the most independent process, MARC, was limited in what information they could provide and relied heavily of the use of default data, especially with respect to the MOVES inputs. The data input elements required for MOVES are shown in Table 4. In PAG's case study, stakeholder working group meetings helped identify detailed data for sub-regional geographies to support their specific sub-regional strategies of interest.

Initially, some questions arose about whether the TEAM results could be used for transportation conformity, because some of the data provided for use in the MOVES analysis was drawn from the data used in the area's most recent regional transportation conformity analysis. Although both analyses rely on some of the same data, TEAM is not part of the transportation conformity process and the TEAM approach does not meet conformity requirements. For example, in the TEAM approach, changes in VMT estimates are generated with TRIMMS rather than the region's travel demand model. However, for conformity purposes, use of a travel demand model is required for certain areas, as well as in any areas where the MPO has a travel demand model.[6] Travel demand models provide vehicle activity estimates beyond the capability of TRIMMS. This detailed activity, such as volumes and speeds on each facility, is then used with MOVES to more precisely estimate emissions. The TEAM analysis is a less rigorous analysis than that required for transportation conformity, as it dispenses with detailed transportation facility classification and associated speed data as used in transportation conformity analyses where areas are required to use a travel demand model. While TEAM can inform an area's overarching conformity discussion about the potential emission benefits of particular strategies, it does not provide results that can be directly used in a regional transportation conformity determination.

2.3. TRIMMS Analysis

The use of the TRIMMS model to estimate VMT reduction has been a standard feature of the TEAM approach since the initial 2010 national study. Several factors recommend using TRIMMS for this type of analysis, including the type and format of inputs required, the geographic scale of analysis, and the capability of modeling a variety of TCMs, making it highly useful for this type of analysis.

The previous study used TRIMMS 2.0; however, the analysis for the 2013 regional study was conducted with TRIMMS 3.0. The Center for Urban Transportation Research (CUTR) at the University of South Florida made some significant changes between these versions. The user interface was updated to reduce the number of steps required to conduct the analysis, and the outputs were expanded in detail. Most significantly, TRIMMS 3.0 added a new land use module that includes controls for increasing residential densities, land use mixing, transit station accessibility, and transit-oriented development (TOD). In the previous version of TRIMMS, land use strategies could be analyzed only by translating them into changes in travel times and travel distances. Further investigation into the TRIMMS 3.0 land use module are required in order to fully understand how this change may account for for the lower response to changes in land use compared to the 2010 study.

TRIMMS strategies are input into three main tables, as shown in the figures below: Employer Demand Management strategies (Figure 1); Financial, Pricing, Access, and Travel Times (Figure 2); and Land Use Controls (Figure 3). The employer demand management inputs work primarily through the use of "radio buttons" where the user selects either yes or no for the application of the strategy. Financial, pricing, access, and travel times are input as numerical values. The land use controls are a mixture of sliding scales, where the user specifies a percentage change from the baseline, and radio buttons.

[6] The conformity rule at 40 CFR 93.122(b) requires the use of travel demand models for serious and above ozone nonattainment and maintenance areas with a population over 200,000; in addition, the rule at 40 CFR 93.122(d) requires MPOs that have a travel demand model to use that model for conformity purposes.

Figure 1: TRIMMS Employer Demand Management Inputs

Program Subsidies

	Yes	No
Carpool Subsidies		
Transit Subsidies		
Vanpool Subsidies		
Bike Subsidies		
Walk Subsidies		

Guaranteed Ride Home and Ride Match

	Yes	No
Carpool matching service offered?		
Emergency ride home provided?		
Vehicle for non-work trips?		

Telework and Flexible Work Schedules

	Yes	No
Flexible working hours offered?		
Compressed work week offered?		
Telework program offered?		

Worksite Characteristics

Accessibility	Yes	No
Bus or train station onsite or within 1/4 mile		
Bike lanes onsite or within 1/4 mile		
Dedicated sidewalk onsite		
Amenities		
Shopping onsite or within 1/4 mile		
Restaurant onsite or within 1/4 mile		
Bank onsite or within 1/4 mile		
Childcare onsite or within 1/4 mile		
Parking		
Parking charge for carpooling?		
Parking charge for vanpooling?		
Number of free onsite parking spaces		0

Program Marketing

	Yes	No
Internal snail-mail of promotional material?		
Internal promotional email?		
Do you hold promotional events		
Program management and promotion (hrs./week)		8

Figure 2: TRIMMS Financial, Pricing, Access, and Travel Times Inputs

Financial and Pricing Strategies ($)

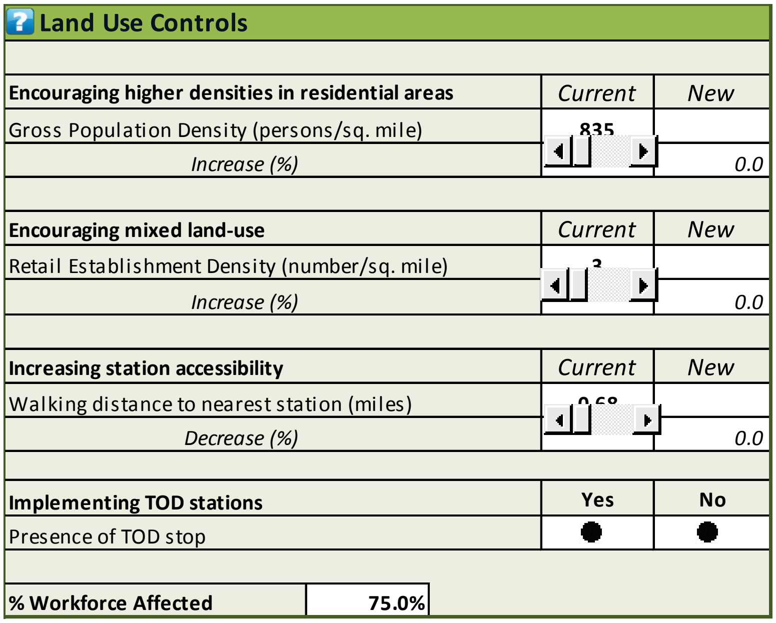
Mode	*Current Parking Cost*	*New Parking Cost*	*Current Trip Cost*	*New Trip Cost*
Auto-Drive Alone				
Auto-Rideshare				
Vanpool				
Public Transport				
Cycling				
Walking				
Other				

Access and Travel Time Improvements (minutes)

Mode	*Current Access Time*	*New Access Time*	*Current Travel Time*	*New Travel Time*
Auto-Drive Alone				
Auto-Rideshare				
Vanpool				
Public Transport				
Cycling				
Walking				
Other				

% Workforce Affected	**85.0%**

Figure 3: TRIMMS Land Use Inputs



Strategy Selection

The three regions selected individual strategies of interest that fit within the TRIMMS analytical capabilities. In general, these fall into the four strategy categories identified in Table 3. Many of the TRIMMS functions work by manipulation of travel times and travel costs, common factors in travel demand modeling. To model an expansion of HOV lanes in TRIMMS, for example, the user must input changes in typical travel times for carpool trips (and possibly single occupancy vehicle (SOV) trips). In order to use TRIMMS effectively, users must consider how to translate their strategy interest into the input options within the model. Table 3 provides information about the data needed and the analysis options within TRIMMS that were used to analyze the strategies selected.

Table 3. TRIMMS Analysis Options

Strategy Categories	Data Needs	TRIMMS Options
TDM or Employer Incentives	• share of regional employees covered • average subsidy offered to employees (by mode) • are guaranteed ride home, ride match, telework, and flexible work schedules offered?	• financial and pricing strategy entries: parking cost and trip cost • program subsidy radio buttons • guaranteed ride home, ride match, telework, and flexible work schedules radio buttons
Transit	• share of regional population affected • average decrease in transit trip cost • transit travel time and access time	• financial and pricing strategy entries: access time and travel time
Land Use	• share of regional population in affected areas • increase in weighted average residential density (persons per square mile) • increase in weighted average retail establishment density (number per square mile) • average decrease in walking distance to transit	• land use controls: residential density, retail establishment density, and walking distance to nearest station
Pricing	• share of all parking (public and private) that is priced • average increase in parking cost per trip • average increase in trip cost	• financial and pricing strategy entries: parking cost and trip cost

Customizing TRIMMS

Elasticities

TRIMMS contains default elasticities that measure the relationship of travel costs and access times to travel patterns. Direct elasticities describe relationships between travel by one mode and the cost and time characteristics of that mode. For example, a direct elasticity of drive alone travel with respect to trip cost of -0.5 means that a 1% increase in drive alone trip cost is associated with a 0.5% *decrease* in drive alone travel. Cross elasticities describe relationships between different modes of travel. A cross elasticity of drive alone travel with respect to transit access times of 1.0 indicates that a 1% decrease in transit access times is associated with a 1% decrease in drive alone travel.

TRIMMS does not provide defaults for all elasticities. For example, TRIMMS 3.0 does not have a default elasticity to represent the shift in drive alone travel relative to the cost of carpool or vanpool travel. TRIMMS supplies zero values for these elasticities, whereas their true values are most likely non-zero. TRIMMS allows the substitution of elasticities for its default values. The national-level research for EPA identified elasticities that are well-supported in the literature. The research team relied upon these values to supplement and support what was available in TRIMMS. The TEAM user guidance identifies the desired elasticities for a regional analysis as well as provides a list of elasticities in its Appendix C.

Still, there are several instances in which elasticities not supplied by either TRIMMS or the literature, and which therefore default to zero, can produce unreasonable analysis results. If the model is run with these values set to zero, the TRIMMS model may predict increases in trips for one mode of travel without corresponding decreases for another mode. TRIMMS automatically rebalances total trip numbers when evaluating employer-based strategies, but not for other strategy types. The user can correct for this by adjusting the outputs of TRIMMS to rebalance total trip numbers (the approach taken in this study, as described below) or by supplying a more complete set of elasticity values.

Alternative Populations and Geographies

In the 2010 national study, TEAM was applied to each region's entire population for all strategies with the exception of TDM, which considered only the working population. However, in the 2013 regional study PAG requested modeling strategies that clearly applied to only a subset of the population and a limited geography within the region. Using TEAM for sub-geographies and sub-populations is more complicated. Sub-geographies and populations sometimes require different baseline assumptions (e.g. mode shares and trip lengths for downtown vs. region), and sub-populations can be difficult to isolate (e.g. traveler population for a specific corridor). Combining strategies that apply to different sub-population or sub-geographies requires that the effects of the strategies be summed together outside of TRIMMS as a post-processing step. In practice this is more likely to overestimate rather than underestimate impacts. When VMT reduction strategies are applied cumulatively within a single model run, the second strategy applies to a smaller baseline VMT than the first strategy, and therefore produces smaller absolute VMT reductions than if applied on its own.

The value of the results using sub-geographies and sub-populations is sometimes limited. The corresponding emissions reductions are quite small when applied to the entire region and may be insignificant even for the limited geography. This type of analysis is more suited to use of a sub-regional model to capture changes in VMT. Regionwide averages and regional scale strategies are more appropriate for TRIMMS and more consistent with the intent and value of TEAM.

However, in some cases modeling for sub-populations and sub-geographies is unavoidable, such as when modeling employer-based strategies. These will naturally apply only to the employed population. In these cases post-processing is essential. For conducting TRIMMS model runs, each scenario was divided into the constituent populations and one model run was conducted for each population. For example, to combine an employer-based strategy with a pricing strategy we conducted two model runs: one run for the employed population, to which both TDM strategies and pricing apply; and one run for the rest of the population, to which only pricing applies. Absolute VMT reductions for each model run were summed together to produce total VMT reductions for the region.

Reasonableness Check

For each case study region, a comparison was made to the results for similar representative regions (based on regional population size and transit mode share) in the 2010 national study. Results for each strategy type for the case study regions were expected to be similar to the results for the comparison representative regions. The aforementioned *Guide to the TEAM Approach* recommended this approach, and these case studies provide an opportunity to test the usefulness of this comparison. Where results for case study regions were dissimilar to those of the comparison region in the 2010 national study, it is noted in the discussion. In some cases, the comparison helped to identify necessary adjustments to the TRIMMS inputs.

2.4. MOVES Analysis

Modeling and post-processing proceeded in stages. First, the actual MOVES runs were conducted, including collection and assembly of all input data and runspec control files, quality assurance and correction of any data issues as necessary and extracting inventory results from the output database. Next, the results were post-processed into a form useable in this analysis. This consisted of converting the inventory values of emissions and activity into regional average, activity-weighted emission factors for each pollutant, vehicle type, and year for the same composite vehicle types used in the TRIMMS analysis. Each of these steps is described more specifically in the sections for each region.

MOVES is EPA’s most current and capable emissions model, and yet is still somewhat unfamiliar to some MPOs. Accordingly, there was varying degree of experience from the three regions on coordinating and collecting the necessary data. The PAG region, in particular, expressed interest in shadowing our analysis, examining all aspects of data collection and processing to further their understanding of the model and its use. Of the three regions, the Boston region MPO showed the most expertise and comfort with the model, and had the most complete input data set. However, their inputs were based on data from a more geographically narrow area than that desired for the TEAM analysis. Accordingly, their data required some modifications for this analysis. MARC was the most straightforward case because little local data was available, necessitating that the analysis be based largely on model defaults. Each of these is discussed more fully in Section 3.

Data Inputs

MOVES allows the user to select the scale and the geographic boundaries for the analysis. When the county scale is chosen, the user can input data specific to the county of interest, or can use the default information within MOVES. Since a TEAM analysis is non-regulatory, there are no restrictions against using default data. However, at the county scale, no default data is available for vehicle type population or for VMT; the user must enter the appropriate local data. Default data is available for other data fields. The MOVES default database includes information that varies by county for fuel and I/M program type, based on survey data at the time the model was developed. It also contains meteorological data for each county and fuel supply and formulation information for each county. For the remaining data fields, the default data are national average data that are then used for the county as-is. For example, using the default age distribution will apply the U.S. average age distribution to the particular county, which may over or underestimate the real age distribution of the county.

Table 4. Data Inputs for MOVES Runs

Data Type Description	Data Elements	
Modeling decision elements that are selected in the MOVES run specification file	Domain/Scale	Geographic Bounds
	Calculation Type	Vehicle Type
	Time Aggregation	Road Type
	Calendar Year	Pollutants and Processes
	Evaluation Month	Strategies
	Type of Day	Activity
	Evaluation Hour	Emissions Detail
Fields for which county-specific data must be entered when using the county scale	Source (Vehicle) Type Population	
	Vehicle Type VMT	
Fields for which MOVES includes default county-specific data	Meteorological Data	
	Fuel Supply/Formulation	
	I/M (Inspection and Maintenance) Program	
Fields for which MOVES includes a national default that can be used for TEAM when county data is unavailable	Age Distribution	
	Ramp Fraction	
	Month, Day, Hour VMT Fractions	
	Average Speed Distribution	
	Alternative Vehicle and Fuel Technology	

The scale selected for MOVES modeling was the county scale, to make use of more precise local data and consistent with EPA Guidance,[7] but the approach varied across the regions. The PAG analysis was performed for the entirety of Pima County. The greater Boston area was modeled as a custom domain encompassing several counties. The seven counties in the MARC region were modeled individually and the results aggregated outside the model. Data collection was focused on each element, as identified in Table 4, for analysis as chosen by each region. Details about the collection, processing, sources, and quality assurance of each of these data items appear in the regional discussions in Section 3.

Deriving Emissions Factors

MOVES was run in inventory mode for each of the regions, and the resulting totals of emissions and activities (VMT and number of starts) were ratioed to produce activity-weighted average emission factors for the region. Four primary pollutants were considered in this analysis: CO_2-Equivalent, NOx, $PM_{2.5}$, and VOC. Other pollutants were also included in the analysis as done in the initial study. These are provided in Appendix B.

As noted above, TRIMMS uses composite vehicle types. Emission factors from MOVES were derived by combining MOVES vehicle types to represent the TRIMMS composite vehicle category definitions.[8] For the TRIMMS auto drive alone and auto rideshare vehicle categories, composite emission factors representing motorcycles, passenger cars, and passenger trucks were combined from the MOVES model. For the TRIMMS vanpool vehicle category, composite emission factors representing MOVES passenger truck and light commercial truck vehicle types were used.

The MOVES analysis included all road types. MOVES emission process types included Start Exhaust, Crankcase Running Exhaust, Crankcase Start Exhaust, Running Exhaust, Brakewear, and Tirewear. All MOVES runs for this project were run without pre-aggregation of the data. While pre-aggregation saves modeling time, it can reduce precision. As recommended by EPA for most purposes, an hourly analysis was performed for all hours, days, months of the year. Emission factors were then calculated as total running emissions (in grams per year) divided by total running activity (in miles per year); a similar analysis was made for starting emissions. Emission factors, in grams of pollutant per average mile driven and grams of pollutant per average start were produced.

From this, a single emission factor was derived for each vehicle type, year, pollutant, and process type. This represents an overall average for that year and was used for every scenario in that year. The current year emission factors were paired with baseline activity in the current year for total baseline emissions, and future year emission factors paired with activity for the

[7] Analysis for scale and other parameters adhered to EPA's current guidance for estimating on-road greenhouse gas emissions: Using MOVES for Estimating State and Local Inventories of On-Road Greenhouse Gas Emissions and Energy Consumption – Final (EPA-420-B-12-068, November 2012).

[8] Other vehicle parameters are also combined within the model. These include fuel type and model year, which are based on the locally specific inputs collected from the regions.

BAU and all scenario alternatives to generate total future year emissions from the BAU and scenarios. Both starting emissions – based on TRIMMS-calculated number of trips – and running emissions – based on TRIMMS-calculated VMT were included in computing the total emissions and emission changes. The calculation of total emissions was done in a simple, off-model spreadsheet calculation that assembled outputs from both the emissions and VMT modeling results. Regionally specific details and results are presented in the Section 3.

3. Case Study Results

Three agencies were selected as case studies for testing the TEAM approach at a regional level: Pima County Association of Governments (PAG), Massachusetts Department of Transportation (MassDOT), and Mid-America Regional Council (MARC). The lead agencies identified stakeholder groups to support their strategy selection and data collection. The selection of strategies was grouped into four scenarios for each region based on their individual interests and data availability. PAG defined its scenarios as four separate strategies with no overlap, in contrast to the other two case study regions, which incrementally applied strategies to achieve a progressive increase in VMT reduction across scenarios. The strategies and their underlying assumptions represent a broad range of potential futures to be evaluated for corresponding changes in travel activity and emissions reductions. Each of the regional analyses are examined in detail in the following sections.

3.1. Pima Association of Governments (PAG) – Tucson, Arizona

Background

PAG is a metropolitan planning organization (MPO) with regional planning responsibilities for transportation, air quality, and water. The organization is governed by a regional council composed of representatives of its member jurisdictions: Pima County, Tucson and South Tucson, the towns of Marana, Sahuarita, Oro Valley, and the Tohono O'odham Nation and Pascua Yaqui Tribe. PAG is responsible for development of the area's long-range regional transportation plan.

PAG has an active travel reduction program which includes voluntary computer based ride-matching for residents and mandatory ride-matching for employers with greater than 100 employees. There is an interest in transit fare and TDM programs. The region's GHG inventory is done every two years, and both county and city have adopted mandates to reduce GHG emissions.

Interest in Participation

When submitting its letter of interest, Pima County was in compliance with the EPA's air quality standards with an ozone level at 90% of the ozone standard, but was concerned that its status could change with a future, more stringent ozone standard. Gathering more accurate information on the emission benefits from travel efficiency strategies can potentially help the region lower VOC and NOx emissions and ultimately ozone concentrations.

Along with the concern about ozone, the region must comply with the requirements in the carbon monoxide Limited Maintenance Plan (CO LMP) due to CO violations in the late 1970's and early 1980's. One of these requirements is to implement a Travel Reduction Program (TRP) for the region to encourage alternate modes of transportation to improve regional air quality. The TRP is administered by PAG staff and has been in effect since 1988, with over 290 companies and organizations participating. The program includes employers in unincorporated Pima County, Tucson, South Tucson, Marana, Oro Valley and Sahuarita. The benefits of the TRP program are quantified by estimated VMT reductions and gasoline savings. PAG is interested in improving staff ability to more precisely estimate the TRP benefits and tailor future planning to promote programs with the most significant pollution benefits. In addition to the TRP, both Tucson and Oro Valley have signed the U.S. Mayor's Climate Protection Agreement committing to reduce GHG emissions to seven percent below 1990 levels by 2012. Both entities have initiated aggressive plans to address this reduction goal.

PAG's initial letter of interest indicated that using the TEAM approach to evaluate travel efficiency strategies could:

- Provide assistance in meeting regional policies and actions such as TRP ordinances and the Mayor's Climate Protection Agreement
- Help to refine actions already underway through the TRP program

- Refine regional transportation-related emissions using the more complex MOVES model, resulting in data that are more closely tracking local conditions and GHG emissions
- Provide an improvement over the Clean Air and Climate Protection model, which does not incorporate speed, local meteorological or travel patterns or vehicle registration data
- Assist PAG's jurisdictions with resource and program planning to select the travel reduction components that allow the greatest air quality benefits

PAG had a specific interest in the use of MOVES for this analysis, and requested permission to "shadow" the analysis effort as a training exercise. This level of interface resulted in more coordination between PAG and EPA to answer questions and resolve issues; however, it also produced a stronger understanding of how the MOVES model can be used for this type of analysis.

Prior Experience with Analysis of GHG Emissions

PAG staff conducts GHG modeling and analyses to develop a *Regional GHG Inventory* for eastern Pima County and the City of Tucson communities and their respective government operations. For the analysis, the most current edition of the inventory was released in 2011 and covers 1990 through 2008. The preliminary results from the 2011 inventory indicate that regional transportation contributed 32 percent to the 2010 Pima County's GHG total. From 1990 to 2010, regional, private/commercial VMT increased by 63 percent with an accompanying 34 percent increase in GHG emissions. In 2010, PAG staff conducted GHG modeling and analyses and developed GHG emission inventories for PAG's outlying jurisdictions (Marana, Oro Valley, and Sahuarita) spanning the 2000-2008 timeframe. PAG staff continues to provide these jurisdictions with GHG emissions and transportation data as requested.

PAG's GHG inventories include emissions from private and commercial vehicles, public transit, government fleet travel and employee commuting, as well as energy use and waste disposal emissions. Private/commercial vehicle emissions are responsible for 99 percent of the region's transportation emissions. Private and commercial VMT data used in the inventories was developed by PAG's transportation planners using their travel demand model. Inventory commuter data are obtained from PAG's annual employee survey. Public transit VMT by fuel type is supplied by the various transit providers. To develop GHG inventories and ongoing GHG analyses, PAG staff uses the Clean Air and Climate Protection (CACP) model and the Climate and Air Pollution Planning Assistant (CAPPA) software developed by the International Council for Local Environmental Initiatives (ICLEI) and others.

The City of Tucson formed the Citizen's Climate Change Advisory Committee in response to the adoption of the U.S. Mayor's Climate Protection Agreement by Tucson's mayor in 2006. The committee developed a report, *Action Plan Tucson, Phase One Climate Mitigation*, passed by the Tucson's Mayor and Council in December 2011. (http://cms3.tucsonaz.gov/sites/default/files/ocsd/act_phase1report_final_6dec11.pdf)

PAG staff conducted the GHG emissions modeling and analyses that were the basis for this report and were instrumental in the development of the technical support document, *Community*

Economic Security and Climate Action Analysis, compiled by Westmorland. Both documents include numerous strategies to reduce emissions through transportation efficiency and land use strategies. Similarly, when the Pima County Board of Supervisors adopted a resolution to develop the *Five-year Action Plan*, implementing wide-ranging strategies aimed at reducing government GHG emissions to 2007 levels by 2020, PAG's GHG inventory data served as the baseline for County government emissions. PAG staff continues to supply GHG emission data and analyses for assessing the plan's progress.

Scenario Development

As the lead agency in the case study, PAG initially expressed an interest in understanding the impact of a variety of strategies on vehicle miles travelled, GHG emissions, and NOx and VOCs in PAG's planning area, including parking cost increases (in the downtown University of Arizona corridor), bike travel increases, bus efficiency improvements, provision of an all-access bus pass for the populations at two academic institutions, incentives for rideshare, and streetcar enhancements.

The existing or base year for the PAG analysis is 2010. The future year is 2040 as reflected in the adopted Regional Transportation Plan (RTP). The BAU scenario provided by PAG included transportation improvement projects included in the plan; it represents the preferred scenario in the RTP. Population and employment in 2040 are estimated to nearly double those of 2010; resulting in substantial increases in travel activity and emissions of some pollutants. Average travel distances will increase under the plan, but walk share will increase too, with more on campus housing being built at the University of Arizona.

PAG was unique in its approach to scenario development. Rather than use the analysis in a cumulative way, building the impacts of one strategy on those of another, the agency wanted to see the specific impacts of each strategy as a stand-alone policy. The rationale for this approach was that the region would not likely adopt all of these measures at the same time, and it would be more meaningful for them to evaluate the benefits of individual strategies.

Much of the PAG data for the TRIMMS analysis was available from the agency's travel demand model. An important stakeholder that was engaged early in the process was SunTran, the regional transit agency. Sun Tran's involvement helped PAG provide the data needed for Scenarios 1 and 3, where transit was a major feature.

Scenario 1 - Implement SunTran All Access Pass

This scenario considers how providing an unlimited ride transit pass for almost 90,000 faculty, staff, and students at the University of Arizona and Pima Community College would affect travel activity. Purchase of the pass would be mandatory, but would be bundled with student tuition and employment benefits, with costs possibly shared between the passholders and the academic institutions. However, the user experience is similar to a case of free transit, since the purchase is non-discretionary, the cost is largely not perceived by the user, and the marginal cost of each additional transit trip is zero.

This strategy did not include an increase in transit service, so bus VMT does not change. This methodology is consistent with the 2010 national study, in which only light-duty vehicle travel is considered and bus VMT is excluded from the results. The TRIMMS analysis used baseline mode shares and trip lengths provided by PAG that are specific to the university populations. The transit pass was modeled as a reduction in transit cost to zero.

Scenario 2 - Expand Employer-Based Incentives for Alternative Commute

About one-third of employees in the region are currently eligible for commute subsidies. This strategy would increase subsidies as shown in Table 5 with all dollar amounts expressed in current year dollars throughout the analysis.

The trip subsidy radio buttons in TRIMMS were used, providing a simple apply/do not apply input. Another option was to use baseline trip costs by mode and adjust these by the subsidy amounts. The research team initially tested this approach using baseline trip costs estimated by the research team, since PAG did not have baseline trip costs. The results of that analysis proved unreasonable, likely due to a combination of incomplete elasticities and underestimated baseline trip costs. In particular, the TRIMMS model lacks a default cross-elasticity for auto drive alone travel with respect to carpool/vanpool trip costs (See Section 2.3).

Scenario 3 - Implement Bus Rapid Transit (BRT) on Two Corridors

PAG is exploring BRT on two major corridors in the region that bring traffic into and out of downtown Tucson: Oracle Road, a north-south corridor, and Broadway Boulevard, an east-west corridor. Although there was no specific data available on the change in transit level of service associated with the BRT proposals, SunTran estimated that the projects might reduce travel times and wait times between transit vehicles by 20% on the corridors.

The PAG-supplied daily traffic counts on both corridors were assumed to be roughly equivalent to traveler population using the assumption of two trips per day (round trips) for this population. The base year traffic counts were then scaled up using projected regional population growth to provide the future year BAU estimate of the traveler population using the two corridors.

Scenario 4 - Expand Parking Pricing in the Downtown-University Corridor

This scenario included a doubling of parking prices in a specific downtown-university area along with expanding the share of parking that is priced in the future year. PAG supplied an estimate of the share of priced parking in the corridor of interest, along with the average parking price per trip. The average price of all priced and unpriced parking in the downtown-university area was estimated as the product of average hourly rates and the proportion of priced parking.

Input parameters are provided in Table 5 for current conditions, a BAU future, and the four scenarios selected by PAG. Specific input values are provided for the scenarios.

Table 5. PAG Scenario Details

Scenario	Description	Geography	Data Used
Current Conditions	Existing conditions across all strategies in 2010	Regionwide and Subarea	• mode shares • average vehicle occupancy • average vehicle trip lengths • regional population and employment • TRIMMS default retail establishment density (0.31 per square mile) • TRIMMS default distance to nearest transit stations (0.70 miles) • parking pricing • employer-based incentives for alternative commute modes
Business as Usual	2040 conditions with current levels of transit pass, employer-based incentives, BRT coverage, and parking pricing	Regionwide	• mode shares • average vehicle occupancy • 2040 regional population and employment • TRIMMS default retail establishment density (0.31 per square mile) • TRIMMS default distance to nearest transit stations (0.70 miles) • Parking cost per trip: $2.71/hr. x 80% population = $2.17/hr. • current employer-based incentives for alternative commute modes • average transit trip cost ($1.43) • average transit travel time (72.46 minutes) • average transit wait time (10 minutes)
Scenario 1: SunTran All Access Pass	Bundle 'free' transit pass with tuition for faculty, staff, and students at two local universities	Regionwide	• number of students, faculty, and staff who will use the pass (86,234) • average transit trip cost ($0)
Scenario 2: Expanded Employer-based Incentives	Increase subsidies by $10-$50 per mode.	Regionwide	• number of regional employees covered (236,616)
Scenario 3: BRT on 2 Corridors	BRT on Oracle Rd and Broadway Blvd.	Subarea	• traveling population affected (62,565) • 20% travel time reduction (to 57.97 minutes) • 20% headway (wait time) reduction (to 8 minutes) •
Scenario 4: Parking Pricing in Downtown-University Corridor	Double parking prices and expand number of priced spaces.	Subarea	• 95% share of all parking (public and private) is priced • parking cost per trip: $5.41/hr. for priced parking x 95% of total parking that is priced= $5.14/hr for all priced and unpriced parking

Additional EPA Land Use Scenario for PAG Region

Unlike MARC and MassDOT, the PAG region did not select a land use strategy as part of its four scenarios. Given the evidence that land use strategies provide an important base for other travel efficiency strategies, a land use strategy was independently developed by EPA for the

PAG region. This land use strategy was analyzed in an additional scenario with the four strategies selected by PAG: a Transit All Access Pass, Expanded Employer-based Strategies, BRT on Two Corridors, and Downtown-University Corridor Parking Pricing.

The land use scenario was defined based on an existing vision for the region: the Imagine Greater Tucson (IGT) preferred land use scenario. IGT developed this scenario through a two-year, community-based visioning process in which residents from across the greater Tucson region communicated their thoughts and opinions on how the region should develop and grow. Over 10,000 people participated in the process and the results show a strong regional desire for smarter growth options.

The regional population growth assumed in PAG's RTP 2040 scenario is roughly equivalent to that assumed in IGT's preferred scenario, and thus provides a consistent reference point for comparison. The IGT scenario concentrates population growth in existing urban centers.

PAG provided data on population densities for all traffic analysis zones (TAZs) in the modeling region for both the IGT scenario and PAG's RTP 2040 scenario. The weighted average population density[9] of the IGT scenario is roughly 50% higher than that of the RTP scenario. Therefore the land use scenario was modeled as a 50% increase in residential density for the region. Since higher residential densities would cluster development in central areas with better transit access, walking distance to the nearest station was reduced by a conservative 10%.

Table 6 provides the results of the analysis of this additional scenario. Adding the land use option increases total region VMT reductions by only 0.25% on top of the other strategies. This result is very small compared to the results of previous analyses of land use strategies using TRIMMS 2.0, and to values estimated in other studies. CUTR has suggested that this result may be due to the relatively low level of transit service in the PAG region, as land use results in TRIMMS are driven by transit accessibility. See Section 4.2 for a further discussion of land use analyses with TRIMMS.

Table 6. Resulting VMT and Emissions Changes for Selected Pollutants

Scenario	Percent Change - 2040 BAU compared to 2040 Scenario				
	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC
Land use changes plus PAG scenarios 1-4	-1.95%	-1.87%	-1.69%	-1.43%	-0.71%

[9] Weighted average population density summarizes regional land use densities in a way that is more representative of residents' daily experience of land use patterns than average density. TAZs with higher populations, which tend to be denser areas, are weighted more heavily than TAZs with lower populations. In the weighted average density calculation, the density of each TAZ in the region is weighted by its proportion of total regional population. An increase in weighted average density does not indicate an increase in total regional population, but rather a shifting of population toward higher density centers.

Emissions Analysis

MOVES2010b was used to determine appropriate emission factors for the PAG regional analysis. Based on information from PAG that 98% of the county's population live within the MPO boundary, the domain was taken as the entirety of Pima County. Input data was provided by PAG and derived from several local, state, and national sources. Table 7 summarizes the MOVES inputs PAG provided and the data used in the final modeling. Table 7 also indicates any modifications to the region-provided data before modeling.

Table 7. PAG Data Sources

Inputs		Region Provided Data		Data Used in Final Modeling	
		Base Year	Future Year	Base Year	Future Year
Source Type (vehicle) Population		x		provided data	Calculated data. Applied the 2010 population/VMT ratio to the 2040 population to get 2040 HPMS VMT totals.
Vehicle Type VMT		x	x	provided data	provided data
Road Type Distribution		x	x	provided data	provided data
Meteorological Data		x		provided data	provided base year data (changed YEAR to 2040)
Age Distribution		x		provided data	provided base year data (changed YEAR to 2040)
VMT Fractions	Hour			MOVES defaults	MOVES defaults
	Day	x	x	provided data	provided data
	Month	x	x	provided data	provided data
Average Speed Distribution		x	x	provided data	provided data
Ramp Fraction				MOVES defaults	MOVES defaults
Fuel	Supply	x	x	provided data	provided data
	Formulation	x	x	provided data	provided data
I/M Program		x	x	modified data: Changed USEIMYN field to N, so that I/M data were not used in modeling.	modified data: Changed USEIMYN field to N, so that I/M data were not used in modeling.
AVFT				MOVES defaults	MOVES defaults

PAG worked closely EPA to determine the locally representative data for the required MOVES inputs. Site-specific data for PAG were very complete, being derived from local, state, and federal modeling and datasets. This is a case of geographically specific strategies that require data specific to that geographic sub-area.

For example, PAG used local data to develop inputs for inspection/maintenance, speed distribution, fuels, and meteorology. During review, concerns were raised about projections of these fields to future years and their effect on results. Ultimately inspection/maintenance data in the analysis was removed due to uncertainty of far-future program design and efficacy on future vehicles and the concern that uncertain I/M influences on emissions could mask other trends. This approach was implemented in all three regional analyses. Baseline year meteorological data provided were also used for the future year, as requested by PAG. Speed distribution values were extracted from the regional TDM modeling data.

PAG also obtained current information from state agencies to develop model inputs. Current fuel information was obtained from the Arizona Department of Weights and Measures (model default fuels were used for future year analyses). Distributions of road type VMT and vehicle ages came from the Arizona Department of Transportation (ADOT). Vehicle population data were developed from ADOT vehicle registrations for Pima County with methods based on EPA guidance[10] for future year vehicle populations. In addition, appropriate local vehicle/road type VMT information and baseline year age distribution data was developed from PAG data, in close coordination with EPA. PAG also coordinated with EPA in use of EPA's MOVES converter tools to derive and/or reformat VMT allocation and speed distribution data, including future year vehicle populations, use of compressed natural gas (CNG) fueled transit buses, and day-type activity factors to create an accurate regional input dataset.

As discovered during initial model runs, when the analysis year is a leap year and the MOVES inputs are selected to pre-aggregate the input data to annual resolution at the county scale, the analyses must be performed with hourly aggregation of inputs.[11] Appendix B discusses this further. No preaggregation was used for the analysis.

Results

The hourly MOVES outputs (for each hour of each day type of each month and year, accounting for the number of hours in each) were manually post-processed to produce annual total emissions (g) and activity (starts or miles). The data were then aggregated to the TRIMMS vehicle types and emission factors were calculated as total emissions divided by total activity, as discussed previously. Table 8 shows the resulting emission factors.[12]

Table 8. Emissions Factors for PAG

	g/mi		g/start	
	Base Year (2010)	Future Year (2040)	Base Year (2010)	Future Year (2040)
Auto (Motorcycles+Passenger Cars+Passenger Trucks)				
GHGs (CO_2-equivalent)	377.22	309.10	117.93	74.88
NOx	0.84	0.14	1.47	0.35
$PM_{2.5}$	0.02	0.01	0.03	0.01
VOCs	0.16	0.03	2.12	0.67

[10] Using MOVES for Estimating State and Local Inventories of On-Road Greenhouse Gas Emissions and Energy Consumption – Final (EPA-420-B-12-068, November 2012).

[11] Note that this issue would not arise in MOVES runs done for official SIP or conformity purposes, as it is not acceptable to pre-aggregate over time for these purposes.

[12] Note that final results omitted Transit emissions. Accordingly, the transit emission factors are not presented in Table 8.

Vanpool (Passenger Trucks+Light Duty Trucks)				
GHGs (CO_2-equivalent)	512.47	383.41	162.37	87.48
NOx	1.80	0.36	2.36	0.44
$PM_{2.5}$	0.04	0.01	0.04	0.01
VOCs	0.33	0.06	3.70	0.62

PAG Scenario Results

Table 9 provides the results of the analysis in terms of total regional impacts. It is important to note that regional reductions are often very modest when compared to the impact on the population targeted by the strategies. Additional explanation is provided on the following page and numerical results are included in Appendix B.

Table 9. PAG Regionwide Percent VMT and Emissions Changes

Percent Change - 2040 BAU compared to 2040 Scenario					
Scenario	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC
Scenario 1: SunTran All Access Pass	-0.99%	-0.97%	-0.94%	-0.86%	-0.77%
Scenario 2: Expanded Employer-based Incentives	-0.43%	-0.43%	-0.42%	-0.40%	-0.44%
Scenario 3: BRT on 2 Corridors	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%
Scenario 4: Parking Pricing in Downtown-University Corridor	-0.26%	-0.25%	-0.25%	-0.24%	-0.26%

- The **SunTran pass** extension has a large impact on the affected population with shifts to transit from SOV: close to a 16% VMT reduction for 90,000 people. More of the mode shift will happen at the University of Arizona, which offers higher transit accessibility. There is the potential to expand to other populations as well, such as residents of downtown and other transit accessible areas.
- **Employer-based incentives** show a more moderate impact on affected population (3% VMT reduction for approximately 240,000 people) with shifts from SOV to carpool, vanpool, transit and cycling.
- **BRT on two corridors** that traverse the region, intersecting in downtown Tucson, shows a small impact on the affected population with only a 0.5% VMT reduction in shifts to transit. This result could be affected by more extensive transit improvements and land use changes.
- **Parking pricing** limited to a small downtown area indicates a moderate impact on the affected population (2% reduction for 400,000 people traveling downtown) with shifts from SOV to carpool, transit, cycling, and walking.

Overall the PAG scenario analysis represents a pragmatic application of potential strategies in the region. Stakeholders were highly interested in feasible scenarios instead of making aggressive assumptions that have a remote chance of being enacted. PAG's selected strategies were limited to specific sub-geographies and sub-populations, whereas other regions applied strategies more broadly and used more aggressive assumptions. PAG also chose not to analyze a land use strategy. Other regions included land use as a foundational strategy in several scenarios, reflecting an understanding of land use as a key strategy to maximize alternative mode options and minimize travel distances. As with any region, the aggressiveness of scenarios is an important decision for lead agencies to make when undertaking a "what if" analysis of this type. The selection of sub-areas and limited affected populations, as well as the lack of a land use foundation for the transit and BRT scenarios contributed to the modest outcome.

PAG has taken a strong interest in the details of this analysis, particularly with respect to the MOVES analysis. This level of involvement and data availability may encourage a repeat of the analysis with changes to the assumptions as an internal exercise in the future. This approach would allow PAG to test impacts before involving a larger group of stakeholders.

3.2. Massachusetts Department of Transportation (MassDOT) – Boston Region

Background

The lead agency for the second regional case study is MassDOT. MassDOT's case study partners include the Metropolitan Area Planning Council (MAPC), the Central Transportation Planning Staff (CTPS, the Boston MPO (BMPO) staff), and the Georgetown Climate Center (GCC). This stakeholder group indicated that HOV lanes, carpool/vanpool incentives, rideshare matching programs, bicycle programs, transit expansion, and smart growth are strategies of priority for the case study.

The BMPO region is the focus of this modeling study, covering 101 cities and towns and approximately 1,405 square miles in the greater Boston region. The region covers more than three million people and includes diverse communities from relatively rural to urban. The base year for the MassDOT regional analysis is 2009 with a future year of 2035. Population and employment data is from the community model domain, which is slightly larger and includes 164 towns and cities in eastern Massachusetts.

Interest in Participation

MassDOT expressed an interest in this study based on the state's strong interest in climate change and GHG emissions reduction. MassDOT has an internal agency GHG emissions target of a 40% reduction from a 2002 baseline (in the GreenDOT Program).The Commonwealth has a general target for GHG reductions across the economy of 25% below 1990 levels, established pursuant to Massachusetts' climate change legislation, the Global Warming Solutions Act. Under the general target, Massachusetts has also established a target for the transportation sector of a 7.1% reduction from a 1990 baseline by 2020.

MassDOT is a participant in the Transportation and Climate Initiative (TCI). The TCI is a regional collaboration of transportation, environment, and energy agencies in 11 Northeast and Mid-Atlantic states, as well as the District of Columbia, that seeks to develop the clean energy economy and reduce GHG emissions in the transportation sector. One of TCI's stated goals is to promote sustainable communities. This project is intended to directly support TCI's work in that area and facilitate the sharing of lessons learned from this effort with other states and metropolitan areas in the region.

Prior Experience with Analysis of GHG Emissions

MassDOT worked with other state agencies and consultants to develop the Massachusetts Clean Energy and Climate Plan 2020, which identified emission reduction potentials from specific strategies in the transportation sector, including from implementation of Sustainable Development principles, implementation of MassDOT's GreenDOT program, and implementation of a Smart Growth policy package. MassDOT has also recently released its GreenDOT implementation plan, identifying the actions MassDOT plans to take to achieve its sustainability goals, including GHG emissions reductions.

The Central Transportation Planning Staff (CTPS) has been incorporating climate change into the planning and programming activities of the MPO through the LRTP and the TIP. The MPO uses its visions and policies established in the LRTP in the project selection process for both documents. Project evaluation criteria are used to identify projects that will help slow climate change through reduction in GHGs and projects that will help adapt to the effects of climate change by addressing flooding or improving evacuation routes. Several discussion papers developed by the MPO previous to this project have considered how projects that reduce GHG emissions can be supported through their programs.

MassDOT is developing performance measures for climate change through the weMove Massachusetts and GreenDOT processes, and the Boston MPO is developing performance measures to demonstrate the region's success in managing their transportation network and the effectiveness of investments in moving towards its visions. The MassDOT and MPO performance measures will be coordinated as required in federal transportation law.

Scenario Development

MAPC developed two land use forecasts for its most recent regional transportation plan, a Current Trends forecast and the MetroFuture forecast. The Current Trends would continue recent historical patterns of land use dispersal in the Boston region, while MetroFuture would concentrate future growth in core areas well-served by transit. In 2008, MAPC adopted MetroFuture as the forecast for its 2030 regional land use plan, which includes supportive implementation strategies. The Boston Region MPO (BRMPO) then adopted the MetroFuture land use scenario in its most recent RTP (adopted in 2011).

All BAU inputs provided by the MassDOT stakeholder group represent a combination of the MetroFuture land use scenario and a no-build transportation scenario. Therefore the BAU scenario already represents a shift from current trends to more smart growth development patterns. The land use scenario incorporated in the BAU forecast clusters more development around transit while no new transit service is provided. Thus, the average transit trip length declines. In addition, mode shares tend to shift from driving to transit and walking given the assumption about new development. Trip lengths for driving trips increase slightly in the future due to some continued dispersal of land uses in the outer areas, despite the emphasis on densification.

The BAU also includes the existing MassRIDES program, the statewide travel options program that partners with employers to provide information about commuting by carpooling, bicycling, walking, public transportation, teleworking, and vanpooling. About 700,000 employees in the Boston region currently have access to MassRIDES programs, which include guaranteed ride home and ride match, telework and flex work programs, and program marketing. Approximately 100,000 of the 700,000 have access to monetary subsidies for healthy modes. For the BAU scenario input, the number of covered employees was scaled by the natural rate of regional employment growth.

Scenario 1 - Expand Programs and Incentives for Healthy Modes

The first MassDOT strategy is based on the existing MassRIDES program, and would increase the number of employees with access to MassRIDES by 25% – giving them access to guaranteed ride home and ride match, telework and flex work programs, and program marketing. The strategy would also expand access to employer-paid monetary subsidies to all employees with access to MassRIDES, who would each receive a subsidy of $70 a month.

This scenario was modeled as two separate strategies: 1) effect on new MassRides users (monetary subsidies and non-monetary benefits) and 2) effect on existing MassRides users (monetary subsidies only).

For monetary subsidies, the baseline trip costs for all modes provided by MassDOT were used, and reduced according to the subsidy amounts, with some modifications. This is in contrast to the radio-button method used for a similar strategy for the PAG region. The actual dollar amounts were able to be used because MassDOT could provide reasonable baseline trip costs for transit and vehicle trips, which included maintenance, tires, gas, and oil. Bicycling and walking subsidies were not explicitly modeled through this method; since both the baseline and final costs of these bicycling and walking trips is assumed to be zero.

For non-monetary benefits, the radio buttons were used for TDM programs and subsidies for *Guaranteed Ride Home and Ride Match* and *Telework and Flexible Work Schedules*.

Scenario 2 - Expand Programs and Incentives for Healthy Modes with Smart Growth Land Use

Scenario 2 adds Smart Growth Land Use to the Scenario 1 strategy. This included an increased emphasis on growth in existing urban centers, in order to increase weighted average residential density, and an increase in land use mixing. [13] The Smart Growth Land Use Strategy represents an increase in weighted average density over that of the MetroFuture forecast, which is incorporated in the BAU. It is therefore not based on any prior detailed analysis or input process. For the strategy, MassDOT suggested doubling the increase in weighted average density between the MetroFuture (BAU) and base year. Although this represents a highly ambitious strategy, it is appropriate for a TEAM analysis of alternative “what if” scenarios.

Population-weighted average density by TAZ was calculated for the entire region for the base year and the MetroFuture 2035 scenario. There is a projected 11% increase in density over this timeframe. Doubling this increased density relative to the base year results in a 22% increase.

Population-weighted average density of retail establishments by TAZ was calculated for the entire region for the base year and the MetroFuture 2035 scenario, and the results showed

[13] Weighted average population density summarizes regional land use densities in a way that is more representative of residents' daily experience of land use patterns than average density. TAZs with higher populations, which tend to be denser areas, are weighted more heavily than TAZs with lower populations. In the weighted average density calculation, the density of each TAZ in the region is weighted by its proportion of total regional population. An increase in weighted average density does not indicate an increase in total regional population, but rather a shifting of population toward higher density centers.

there is effectively no density increase projected. MassDOT instructed that the scenario should increase density relative to the base year by 10%.

MassDOT did not have an immediately available method to estimate the change in average walking distance to transit, so this was not modeled in TRIMMS. However, with the increased density envisioned in this scenario, this distance would decrease. Had it been modeled, it may have reduced VMT and emissions further.

The TRIMMS model run for this scenario only includes land use changes, and the entire regional population is affected. The Healthy modes strategy was added in as a post-processing step. For residential population density, MassDOT provided the figures 10,205 people per square mile (BAU) and 11,230 people per square mile (scenario). TRIMMS default density figures are lower, because they are based on an unweighted density calculation, which gives equal weight to low and high density TAZs. Adjustments to the default baseline density in TRIMMS are not easily customizable; however, since the percentage increase drives the modeling results, the calculated increase can be applied to the TRIMMS default figure. Therefore an increase of 20% was applied to the TRIMMS default baseline. (The actual increase calculated was 22%, but TRIMMS only allows increases in 5% increments).

For retail establishment density, MassDOT provided estimates of 698 establishments per square mile (BAU) and 762 establishments per square mile (scenario). The TRIMMS default value was increased by 10% for the scenario.

Scenario 3 - Expand Programs and Incentives for Healthy Modes with Smart Growth Land Use and HOV Lanes

The scenario adds HOV lanes to the previously analyzed strategies with a decrease in rideshare travel time by 10% for entire region through a network of HOV lanes. The HOV lanes strategy is not based on any specific proposal or plan. Parameters represent a hypothetical scenario, developed through internal conversations at MassDOT. The assumptions appear to be reasonable, given that they represent roughly a return to the 2009 base year travel time value.

The TRIMMS model run for this scenario includes HOV lanes and land use changes (Scenario 2), since these both affect the entire regional population. As in Scenario 2, Healthy modes was added in as a post-processing step. The resulting reduction in SOV VMT reported was less than the increase in rideshare VMT; a counter-intuitive result. In order to capture the reduction in SOV VMT, rideshare VMT was held constant in post-processing. The response of TRIMMS to this analysis will be discussed more fully in the conclusions and recommendations.

Scenario 4 - Expand Programs and Incentives for Healthy Modes with Smart Growth Land Use, HOV Lanes and Transit Network Expansion and Improvement

The final MassDOT scenario adds transit network expansion and improvement to the previous analyses. This strategy is expected to reduce both transit trip times and access times (wait times) for regional population by 10%. The strategy is not based on any specific regional proposal or plan. Parameters represent a hypothetical scenario, developed through internal conversations at MassDOT. MBTA has approximately 15 key bus routes, some or all of which could be upgraded to a BRT level of service, as part of the strategy. The model run includes transit network, land use changes (Scenario 2) and HOV lanes (Scenario 3). As in Scenarios 2 and 3, Healthy modes were added in as a post-processing step.

Input parameters are provided in Table 10 for current conditions, a BAU future, and the four scenarios selected by MassDOT. Specific input values are provided for the scenarios.

Table 10. MassDOT Scenario Details

Scenario	Description	Geography	Data Needs
Current Conditions	Existing conditions across all strategies in 2009	Regionwide	• mode shares • average vehicle occupancy • average vehicle trip lengths • TRIMMS default vehicle ownership (1.72 vehicles/household) • regional population and employment • employer-based incentives for alternative commute modes
Business as Usual	2035 conditions with current levels of employer program, land use, HOV lanes, and transit; future growth assumed to be focused in areas served by transit (the “Metro Futures” land use forecast)	Regionwide	• mode shares • average vehicle occupancy • average vehicle trip lengths • 2035 regional population and employment • current employer-based incentives for alternative commute modes • TRIMMS default vehicle ownership (1.72 vehicles/household) • current travel times (23.4 minutes for rideshare and 24.5 minutes for transit) • current transit access times (10.5 minutes) • current trip costs ($2.08 for rideshare, $4.00 for vanpool, and $1.60 for transit) • residential population density (10,205 persons per square mile) • retail establishment density (698 per square mile)
Scenario 1: Expanded Healthy Modes Program	Expand the statewide travel options program that partners with employers to provide information about commuting by alternate modes of transportation.	Regionwide	• number of regional employees covered (652,565 existing users, 152,265 new users) • average monthly subsidy offered to employees ($70 for rideshare, vanpool, and transit) • are guaranteed ride home, ride match, telework, and flexible work schedules offered?
Scenario 2: Scenario 1 + Land Use	Increase residential density and mixed use land uses in selected areas.	Regionwide	• 22% increase in population density (to 11,230 persons per square mile) • 10% increase in retail establishment density (to 762 per square mile)
Scenario 3: Scenario 2 + HOV Lanes	Add HOV lanes.	Regionwide	• rideshare travel time reduction (10% reduction to 21.1 minutes)
Scenario 4: Scenario 3 + Expanded Transit	Expand transit network and improve transit infrastructure.	Regionwide	• 10% transit travel time reduction (22.1 minutes) • 10% headway (wait time) reduction (to 9.5 minutes

Emissions Analysis

As previously described, MOVES2010b was used to determine appropriate emission factors for the MassDOT scenario analysis. This region was modeled as a single-zone, custom domain to capture the BMPO region of jurisdiction and best utilize the available input data:[14]

The BMPO regional boundary does not coincide well with county boundaries, including all or parts of seven counties. The MOVES analysis experience and capability in the region is well advanced, including previous modeling for several years and detailed inputs ready for use, but based on data for a single county, Middlesex. Their MOVES experience has focused on emission rates for this county for CAA purposes instead of an emission inventory approach as used in this study.[15] With this approach, emission rates from the representative county can be applied to activity from other counties, as long as they have the same fuels and I/M program as the representative county. That is the case for this region. Therefore most inputs provided were based on Middlesex County, except source population and total VMT (the two MOVES inputs that must be totals), which CTPS provided for the whole MPO rather than split into each of the seven counties.

Given the available data, it made sense to model the region as a “custom domain” in MOVES rather than model the counties individually. In the county scale, the custom domain option allows the user to model a multi-county area using one run. Executing a custom domain requires that some MOVES inputs be formatted slightly differently than county-scale inputs, but otherwise the run execution is similar to that of a county-scale run. Table 11 summarizes the MOVES inputs that MassDOT provided and the data used in the final modeling. Table 11 also indicates if any modifications to the region-provided data were made before modeling.

Table 11. MassDOT Data Sources

Inputs	Region Provided Data		Data Used in Final Modeling	
	Base Year	Future Year	Base Year	Future Year
Source Type Population	*x	*x	*provided data	*provided data
Vehicle Type VMT	*x	*x	*provided data with change: calculated VMT from provided data by annualizing, summing auto+truck, and allocating across source types using factors from region.	*provided data with change: calculated VMTs from provided data by annualizing, summing auto+truck, and allocating across source types using factors from region.
Road Type Distribution	x	x	provided data	provided data
Meteorological Data	x	x	provided data with change: ZONEID was changed to 1	provided data with change: ZONEID was changed to 1

14 http://www.ctps.org/Drupal/mpo. Other options include single county (as for PAG), or series of individual counties (as for MARC).

15 Either MOVES calculation type, Inventory or Emission Rates, is acceptable for regulatory purposes; the emission factors within the model are the same regardless of calculation type chosen.

Inputs		Region Provided Data		Data Used in Final Modeling	
		Base Year	Future Year	Base Year	Future Year
Age Distribution		x		provided data with change: YEARID was changed to 2009	provided data with change: YEARID was changed to 2035
VMT Fractions	Hour	x	x	provided data	provided data
	Day	x	x	provided data	provided data
	Month	x	x	provided data with change: ISLEAPYEAR was changed to N	provided data
Average Speed Distribution		x	x	provided data	provided data
Ramp Fraction		x	x	provided data	provided data
Fuel	Supply	x	x	**provided data with change: FUELYEARID was changed to 2009 and COUNTYID was changed to 99001	**provided data with change: COUNTYID was changed to 99001
	Formulation	x	x	provided data	provided data
I/M Program		x	x	**provided data with change: YEARID was changed to 2009, STATEID was changed to 99, COUNTYID was changed to 99001, and USEIMYN was changed to N.	**provided data with change: YEARID was changed to 2009, STATEID was changed to 99, COUNTYID was changed to 99001, and USEIMYN was changed to N.
AVFT				MOVES defaults	MOVES defaults
**Zone				All factors set to 1 because modeling used only one zone	All factors set to 1 because modeling used only one zone
**Zone Road Type				All factors set to 1 because modeling used only one zone	All factors set to 1 because modeling used only one zone

* MassDOT provided inputs for Source Type Population and Vehicle Type VMT for the entire domain in aggregate (not subset by county). All other provided inputs were specific only to Middlesex County.

** Because the MassDOT MOVES modeling used a custom domain, a zone (with arbitrary ID ‘1’) was used in the modeling, requiring the ZONEID to be set to 1 in the meteorology data and arbitrary STATEIDs and COUNTYIDs of 99 and 99001, respectively, in inspection/maintenance and fuel supply inputs. Custom-domain runs also require the Zone and ZoneRoadType input sheets, which were not provided by MassDOT but contained zone allocation factors that were all set to 1 because the domain included only one zone.

Lessons Learned

The MassDOT case study provides a good example of how a TEAM analysis can be done when the region of interest covers multiple counties but the available data is not provided for each county. MassDOT provided most of the other MOVES inputs for a single county in the domain (Middlesex County), which represents the seven-county region in terms of the MOVES parameters such as fuels used, fleet age distribution, road type distribution, etc. Although much of the Middlesex County data was provided for year 2012, it was taken as representative of 2009, so the value of the YEAR field was changed to 2009 where necessary. Age distribution data were only provided for the base year, so the same data were reused for future year by changing the YEAR field. Ultimately inspection/maintenance (I/M) was excluded from the model results by setting the USEIMYN field to ‘N’. MOVES default data were used for alternative fuels and technology. This was done to remove uncertainty in future program design and efficacy of I/M for future vehicles, as well as the concern that uncertain I/M influences could mask other trends.

To capture the entire domain with input data provided for a single county, we ran the MOVES model, specifying inputs for a custom modeling domain that covers the entire region of the study (parts or whole of 7 counties: Middlesex, Suffolk, Norfolk, Plymouth, Essex, Worcester, Bristol) using provided inputs for Middlesex that are applicable to the entire region and provided regional totals for other fields (population and VMT) as appropriate. The setup for a custom-domain run is nearly identical to that of a county-level run, and documented in the MOVES User's Guide,[16] except for some minor reformats of some of the input sheets. It also uses a different Geographical Bounds specification and two additional input sheets (Zone and ZoneRoadType) with allocation factors that are all set to 1 for a single-zone custom domain such as the application here.

Summary of Results

The post-processing of hourly MOVES outputs to domain-wide, average emission factors for the MassDOT case study were calculated as described previously. Total running emissions from hourly outputs (in grams per year) were divided by total running activity (in miles per year) to produce regional and annual average, g/mile emission factors. A similar analysis was made for starting emissions. The resulting emission factors, in grams of pollutant per average mile driven or grams of pollutant per average start are shown in Table 12.

Table 12. Emission Factors for MassDOT

	g/mi		g/start	
	Base Year (2009)	Future Year (2035)	Base Year (2009)	Future Year (2035)
Auto (Motorcycles+Passenger Cars+Passenger Trucks)				
GHGs (CO_2-equivalent)	418.16	316.97	160.18	106.41
NOx	0.85	0.17	1.77	0.46
$PM_{2.5}$	0.02	0.02	0.04	0.02
VOCs	0.16	0.03	2.68	0.71
Vanpool (Passenger Trucks+Light Duty Trucks)				
GHGs (CO_2-equivalent)	510.61	373.36	191.76	118.59
NOx	1.28	0.31	2.46	0.52
$PM_{2.5}$	0.03	0.02	0.04	0.02
VOCs	0.23	0.05	3.33	0.61

[16] Motor Vehicle Emission Simulator (MOVES): User Guide for MOVES2010b, EPA-420-B-12-001b, June 2012.

MassDOT Scenario Results

Table 13 provides the regional results of the analysis. The MassDOT results are similar to the results of the 2010 national study for regions similar to Boston. Note that regional reductions are often modest when compared to the impact on the population targeted by the strategies where the impact is much greater. Additional explanation is provided on the following page and numerical results are included in Appendix B.

Table 13. MassDOT Regionwide PercentVMT and Emissions Changes

Percent Change for 2035 BAU compared to 2035 Scenario					
Scenario	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC
Scenario 1: Expanded Healthy Modes Program	-2.80%	-2.80%	-2.80%	-2.79%	-2.77%
Scenario 2: Scenario 1 + Land Use	-3.89%	-3.89%	-3.88%	-3.88%	-3.84%
Scenario 3: Scenario 2 + HOV Lanes	-4.07%	-4.06%	-4.06%	-4.05%	-4.02%
Scenario 4: Scenario 3 + Expanded Transit	-4.41%	-4.41%	-4.40%	-4.39%	-4.36%

- The **Healthy Modes** scenario shows a large impact on the affected population with about 16% reduction in VMT for existing MassRides users (650,000 people) and 20% reduction in VMT for new users (150,000 people). The shifts occur from drive-alone to rideshare, cycling and walking. When the entire population of the region is considered rather than just the affected population, the results are more modest, as shown in Table 13.
- For the **land use** strategy the VMT impacts are much greater for MassDOT than they were for PAG, and more consistent with current literature. Land use impacts may be more reasonable for MassDOT because Boston is a transit rich region, and the TRIMMS land use algorithms focus on transit ridership as the impact of land use densification. There is a moderate impact on regional population (1% VMT reduction) that results from a reduction of drive-alone trips. However, as noted earlier, the change in average walking distance to transit that resulted from the land use strategy was not modeled; had it been, greater reductions may have been seen.
- **HOV Lanes** show small impacts with shifts from drive-alone to carpool.
- **Transit network improvements** also show small impacts. While Boston has a robust transit system, transit still accounts for only 7-8% of trips. Therefore impacts of transit improvements are applied to a small baseline.
- The HOV strategy represents a reduction in rideshare travel times. The TRIMMS analysis showed a reduction in SOV VMT less than the increase in rideshare VMT; which is unexpected. This is a result of TRIMMS' lack of controls on trip totals for analysis of pricing strategies (discussed further in Section 4). This was adjusted in post-processing by removing the increase in VMT due to rideshare. Making this adjustment produces a reduction in VMT that is consistent with the literature reviewed for the previous TEAM analysis.

Non-SOV travel subsidies can be effectively modeled using dollar values rather than the radio buttons if reasonable baseline trip costs and elasticities are supplied. The dollar value approach was used for MassDOT. This approach will tend to produce larger VMT reductions in TRIMMS compared to the radio buttons, especially if combined with non-monetary employer-based programs. TRIMMS' standard functions for employer-based strategies, which use on/off buttons for subsidies, use more conservative assumptions to model impacts. However, use of actual dollar amounts allows the impact to vary with the subsidy amount.

3.3. Mid-America Regional Council (MARC) – Greater Kansas City

Background

MARC is a coordination entity and the metropolitan planning organization for the bistate region of Kansas City (Kansas and Missouri). The MARC region consists of 9 counties and 120 municipalities, but the transportation planning boundary is slightly smaller and the air quality boundary is even smaller. The staff works with two different state DOTs and two different air quality offices.

MARC is responsible for the long range regional transportation plan for the region, as well as many other planning and coordination initiatives. The LRTP, *Transportation Outlook 2040*, was adopted by the MARC Board of Directors and included, for the first time, a GHG goal as a fundamental element of the policy framework. During the same timeframe, the region's voluntary Clean Air Action Plan underwent a comprehensive update and included co-benefit analysis of recommended measures including reduction of GHGs. MARC is in danger of violating the 2008 75ppb ozone standard after the completion of the 2012 ozone season and understands the importance of credible assessments of travel efficiency strategies to help attain the federal standards and estimate the additional benefits of GHG emission reductions.

Interest in Participation

For this study, MARC expressed an interest in investigating a combination of land use controls, transit-oriented development and smart growth; expansion of transit service; rideshare; and road pricing. The agency would like to be able to use the results from this study to inform the LRTP.

The MARC region is already active in operational improvements using strategies such as ramp metering, ITS infrastructure, signal prioritization and others. Most travel strategies for the region relate to congestion mitigation rather than VMT reduction. Although their goal in the past has been to build more lanes to add capacity, this study represents a shift in focus in order to get more support for VMT reduction. In addition, MARC anticipates the potential need to develop a SIP, and this study could identify specific measures to include.

Prior Experience with Analysis of GHG Emissions

Transportation Outlook 2040 included two alternative 2040 land-use scenarios that were subjected to several analyses, including trip travel time, roadway congestion, and cost of new infrastructure. Parsons Brinkerhoff evaluated the scenarios for their anticipated energy consumption and GHG emissions using the scenario-analysis tool called CarbonFIT, a model built on the platform of CommunityViz. Although the region has demonstrated an interest in GHG and climate change, MARC has not yet set specific goals in this regard.

Scenario Development

The MARC base year is 2010 with a future year of 2040. MARC was able to provide only a limited amount of data, so TRIMMS defaults were used heavily. MARC produced three land use forecasts during the development of the long range plan. These are:

- **Current Trends**: continuing recent historical patterns of sprawling land uses
- **Adaptive Scenario:** focusing growth in the core areas
- **Adopted Scenario**: representing the compromise between Current Trends and Adaptive that was adopted by the MPO board

MARC provided BAU outputs from its travel demand model for year 2040. For land use, the BAU outputs use the *Current Trends* forecast rather than the Adopted Scenario. This approach is in contrast to the land use scenario Boston included in the BAU, and was chosen so that the all smart growth improvements could be analyzed. For transportation, the BAU outputs represent a build scenario, including all the projects identified in the most recent long range transportation plan, with a horizon year of 2040. The modeled mode shares are almost unchanged from 2010 to 2040, because the transportation investments in the plan supply additional roadway and transit facilities in proportion to the population growth, and consistent with existing travel patterns.

Scenario 1 - Expand Ridesharing and TDM programs

About 50,000 employees in the region have access to telework and flexwork programs, Guaranteed Ride Home and ridematching services. (A regional ridesharing program includes 14,000 participants). The strategy expands the number of people covered by the program from 50,000 to 300,000, an increase of 500%. It also adds alternative mode subsidies for the 300,000 people covered from the current $25 to $50 dollars per month. Population figures were scaled based on the natural rate of job growth in the region.

This was modeled as two strategies in TRIMMS: 1) telework and flex work plus TDM programs (non-monetary only) and 2) subsidize work trips using alternate modes plus other programs (both monetary and non-monetary). For non-monetary strategies, the radio buttons for TDM programs and subsidies for *Guaranteed Ride Home and Ride Match* and *Telework and Flexible Work Schedules* were used. For monetary subsidies, MassDOT's BAU trip costs were substituted as reasonable proxies for trip costs in the MARC region, which were not available from MARC. In reality trip costs are likely to be higher in the MassDOT region, where average trip lengths are longer and tolling is more prevalent. However, using higher baseline trip costs errs on the conservative side when modeling VMT reductions, since the subsidy amounts examined will be smaller in relative terms.

Scenario 2 - Expand Ridesharing and TDM programs along with Transit Improvement and Promotion

This scenario adds transit improvement and promotion by reducing transit trip times by 20%, reducing walking distance to transit by 50% and expanding the successful university transit pass program (U-Pass) to 6% of total regional population. SmartMoves, the regional transit vision updated in 2008, would support this strategy. Ridesharing and TDM programs were not included in the model run. Rather the impact of expanded ridesharing and TDM programs was summed with these TRIMMS model runs as a post-processing step. Because base year values were not available from MARC, substitute base year values from the 2010 national study for a similar metropolitan area (San Diego) were used.

As in Scenario 1 this was modeled as two strategies in TRIMMS: 1) reduce transit trip times and walking distance only and 2) university transit pass program with reduced transit trips times and walking distance. TRIMMS does not allow specific adjustment of walking distance to transit. It uses percentage reductions from the provided default walking distance. The default value of 1.26 miles was used and decreased by 50% for the scenario. For the second scenario, a baseline transit trip cost of $1.50 was used, based on fare information on the KCATA website.[17] In the scenario, the transit trip cost is $0, reflecting the marginal cost of each transit trip to the pass holder. This is not to say that the transit pass would be free, but in the scenario the transit pass costs are assumed to be bundled with tuition or employment benefits.

Scenario 3 - Expand Ridesharing and TDM programs, Transit Improvement and Promotion with Smart Growth Land Use

Scenario 3 adds smart growth land use to the previous strategies. The smart growth land use strategy represents a shift from the region's Current Trends scenario (incorporated in the BAU) to their Adaptive scenario. This increases weighted average residential density[18] and mixed use land uses for the entire region. Thus, the entire regional population is affected.

MARC provided population densities by TAZ, from which population-weighted average density by TAZ was calculated. The TRIMMS default for retail establishment per square mile for the Kansas City region is 0.82. MARC provided retail employment/acre by TAZ. Weighted average density figures were calculated, and the percent change was applied to the TRIMMS default.

For residential population density, MARC provided the figures 2,655 people per square mile (BAU) and 3,693 people per square mile (scenario). After rounding these figures to units allowed by TRIMMS, the scenario population density was modeled as a 40% increase above the BAU population density. For retail establishment density, MARC provided the figures 0.45 establishments per square mile (BAU) and 0.71 establishments per square mile (scenario). Similarly, after rounding, the BAU retail density was increased by 55% for the scenario. The VMT impacts for land use are considerably lower than expected.

[17] http://www.kcata.org/fares/

[18] Weighted average population density summarizes regional land use densities in a way that is more representative of residents' daily experience of land use patterns than average density. TAZs with higher populations, which tend to be denser areas, are weighted more heavily than TAZs with lower populations. In the weighted average density calculation, the density of each TAZ in the region is weighted by its proportion of total regional population. An increase in weighted average density does not indicate an increase in total regional population, but rather a shifting of population toward higher density centers.

Scenario 4 - Expand Ridesharing and TDM programs, Transit Improvement and Promotion, Smart Growth Land Use and Transportation Pricing

The final scenario adds transportation pricing as an increase in the average cost of auto trips by 100% and increase parking costs by 500% in the Downtown Area. Currently about 1% of regional parking is priced. This was expanded to 6% of total regional parking.

BAU trip costs represents the average fuel cost/mile for a sedan from AAA[19] and the average trip length for Kansas City. Relative to fuel costs only, the scenario represents approximately a 25 cent per mile charge. The rideshare trip cost was adjusted for vehicle occupancy. BAU parking cost is based on similar metropolitan areas from Colliers Parking Rate Survey.[20] The rideshare parking cost was assumed to be the same as auto-drive alone parking cost.

This was again modeled as two strategies: 1) parking pricing for 6% of the regional population and mileage pricing and 2) mileage pricing for the remaining 94% of the regional population. Initially, the entire scenario was applied regionwide by calculating average regionwide parking price as an intermediate step. However, this produced an unreasonable outcome because it results in an enormous relative increase in average parking cost. Instead, the parking strategy was modeled only for the sub-area to which it applies in order to reasonably limit the impact.

Both strategies modeled include land use changes and transit improvement. TDM and university transit pass (part of transit improvement and promotion) were added in as a post-processing step

Input parameters are provided in Table 14 for current conditions, a business as usual future, and the four scenarios selected by MARC. Specific input values are provided for the scenarios.

[19] http://fuelgaugereport.aaa.com/?redirectto=http://fuelgaugereport.opisnet.com/index.asp

[20] http://www.colliers.com/~/media/files/marketresearch/unitedstates/colliers_2012_na_parking_survey.pdf

Table 14. MARC Scenario Details

Scenario	Description	Geography	Data Inputs
Current Conditions	Existing conditions across all strategies in 2010	Regionwide	• mode shares • average vehicle occupancy • average vehicle trip lengths • regional population and employment • TRIMMS default vehicle ownership (1.71 vehicles/household) • employer-based incentives for alternative commute modes
Business as Usual	2040 conditions with current levels of employer program, land use, HOV lanes, and transit	Regionwide	• mode shares • average vehicle occupancy • TRIMMS default vehicle ownership (1.69 vehicles/household) • 2040 regional population and employment • current employer-based incentives for alternative commute modes • current travel times (50 minutes for transit) • walking distance to nearest transit station (1.26 miles) • average parking costs ($10 for drive-alone and $4.26 for rideshare) • average trip costs ($2.41 for drive alone, $2.08 for rideshare, $4 for vanpool, and $1.50 for transit) • residential population density (2,655 persons per square mile) • retail establishment density (0.45 per square mile)
Scenario 1: Expanded TDM	Expand access to telework and flexwork programs, Guaranteed Ride Home and ridematching services.	Regionwide	• share of regional employees covered (65,181 for non-monetary subsidies only and 300,000 for all subsidies) • average monthly subsidy offered to employees ($50 for rideshare, vanpool, and transit) • are guaranteed ride home, ride match, telework, and flexible work schedules offered?
Scenario 2: Scenario 1 + Enhanced Transit	Improve transit and expand transit pass program.	Regionwide	• 20% travel time reduction (to 40 minutes) • 50% decrease in walking distance to nearest transit station (to 0.63 miles) • Number of regional employees covered by university transit pass program (134,834) • average transit trip cost for university transit pass ($0)
Scenario 3: Scenario 2 + Land Use	Increase residential density and mixed use land uses for entire regional population.	Regionwide	• 39% increase in population density (to 3,693 persons per square mile) • 57% increase in retail establishment density (to 0.71 per square mile)
Scenario 4: Scenario 3 + Pricing	Implement mileage pricing and increase and expand coverage of parking costs.	Regionwide	• 6% of all parking (public and private) is priced • 500% increase in average parking cost per trip (to $60 for drive-alone and to $25.53 for rideshare) • 100% increase in average cost per trip (to $4.82 for drive alone and to $4.16 for rideshare)

Emissions Analysis

MARC provided a variety MOVES input data at county-level resolution for the seven counties in the MPO. However, this data only covered a small portion of the required inputs for MOVES, so a large amount of default data was included in the analysis. MOVES was run at the county scale for each county and year individually. The final calculated emission factors were then calculated for the domain as a whole by aggregating the MOVES results from each county. MOVES outputs for amounts of emissions and activity were summed across the seven counties, creating domain totals, and the ratio of emissions to activity created domain-wide emission factors. This approach required greater effort in data collection and manipulation, file management, model setup and runtime, and post-processing, but incorporated all the provided data to produce the regional average used in this approach. Table 15 summarizes the data MARC provided and used in the MOVES simulations, and any modifications made to the data before modeling.

Table 15. MARC Data Sources

Inputs		Region Provided Data		Data Used in Final Modeling	
		Base Year	Future Year	Base Year	Future Year
Source Type Population				MOVES defaults*	MOVES defaults*
Vehicle Type VMT				MOVES defaults*	MOVES defaults*
Road Type Distribution		x	x	provided data	provided data
Meteorological Data				MOVES defaults	MOVES defaults
Age Distribution		x		provided data	provided baseline year data with change: YEARID was changed to 2040
VMT Fractions	Hour	x	x	provided data	provided data
	Day			MOVES defaults	MOVES defaults
	Month			MOVES defaults	MOVES defaults
Average Speed Distribution		x	x	provided data	provided data
Ramp Fraction				MOVES defaults	MOVES defaults
Fuel	Supply			MOVES defaults	MOVES defaults
	Formulation			MOVES defaults	MOVES defaults
I/M Program				no data: these counties do not require emissions inspections	no data: these counties do not require emissions inspections
AVFT		x (Kansas only)		provided data for Kansas counties. 2008 values repeated for 2009 and 2010; MOVES defaults for Missouri counties	MOVES defaults

*MOVES defaults for these inputscan be generated from a national scale run

Lessons Learned

The MARC case study is a good example of how emission factors can be estimated for a multi-county domain when at least some county-level data are available. MARC did not provide several of the most critical MOVES inputs, including vehicle populations and total VMT by vehicle type. MARC also did not provide data for meteorology, ramp fraction, monthly and daily VMT allocations, or fuel supply and formulation. Each of these were modeled with MOVES-derived defaults. I/M is not required for these counties and was not included in the analysis. MARC did provide road type VMT and speed distribution data for all counties and years. For the remaining inputs—age distribution and alternative fuels and technologies—MARC provided data for some years and/or some counties, and otherwise defaults were used or both years shared the same values, depending on the input.

In some cases, the year of provided data did not agree with the baseline year and had to be modified. In these cases, any local inputs provided were translated to the baseline year and any default values were re-extracted for the baseline year. Notably, the AVFT values were provided for the counties in Kansas but only extending to 2008. To update to the baseline 2010 year, the last year of provided data was repeated for 2009 and 2010. This approach was selected given the preference to rely on local data whenever possible, the reasonable doubt that there would be a significant change across the most recent three years, and the consistency maintained by using local data for all the years.

Finally, no local traffic, vehicle registration, or other DOT information was available to derive source populations and VMT totals. Instead, national scale MOVES simulations were performed for each county of interest to extract defaults for these values, which were then re-imported to the county-scale runs. This is less ideal than using local data. The data for age distribution and alternative fuels and technologies could also be more complete, instead of a mix of local and default data. However, the case does serve as a demonstration of this method with very limited local input values.

Summary of Results

The post-processing of hourly MOVES outputs to domain-average emission factors for the MARC case used the same methods as discussed for PAG, except that the emissions and activity were aggregated across all seven counties before domain-wide, activity-weighted, emission factors were calculated. The resulting emission factors are shown in Table 16.

Table 16. Emission factors for MARC

	g/mi		g/start	
	Base Year (2010)	Future Year (2040)	Base Year (2010)	Future Year (2040)
Auto (Motorcycles+Passenger Cars+Passenger Trucks)				
GHGs (CO_2-equivalent)	398.53	291.07	153.99	97.94
NOx	0.90	0.14	1.76	0.40
$PM_{2.5}$	0.03	0.01	0.04	0.02
VOCs	0.18	0.03	2.51	0.68
Vanpool (Passenger Trucks+Light Duty Trucks)				
GHGs (CO_2-equivalent)	509.56	361.64	181.22	110.55
NOx	1.50	0.30	2.34	0.49
$PM_{2.5}$	0.05	0.02	0.05	0.02
VOCs	0.28	0.05	3.06	0.59

MARC Scenario Results

Table 17 provides the regional results of the analysis. As noted earlier, regional reductions are often modest when compared to the impact on the population targeted by the strategies. Additional explanation is provided below and numerical results are included in Appendix B.

Table 17. MARC Regionwide Percent VMT and Emissions Changes

Percent Change for 2040 BAU compared to 2040 Scenario					
Scenario	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC
MARC					
Scenario 1: Expanded TDM	-0.93%	-0.93%	-0.93%	-0.92%	-0.92%
Scenario 2: Scenario 1 + Enhanced Transit	-2.35%	-2.35%	-2.35%	-2.35%	-2.34%
Scenario 3: Scenario 2 + Land Use	-2.49%	-2.49%	-2.49%	-2.48%	-2.48%
Scenario 4: Scenario 3 + Pricing	-12.06%	-12.05%	-12.05%	-12.03%	-12.02%

Ridesharing and TDM have a moderate impact on affected population with a 3.6% VMT reduction and shifts from drive-alone to rideshare, cycling, walking and transit.

Transit improvements have a small impact on affected population (0.5% VMT reduction) for transit trip times and walking distance. However, there is a large impact on affected population for university transit pass (18.3% VMT reduction) with shifts from drive-alone and rideshare to transit.

Land use also shows a small impact on affected population (0.14% VMT reduction) with shifts from drive-alone to transit. This is an unreasonably small impact, similar to that observed for PAG. CUTR has suggested that this result may be due to the relatively low level of transit service in the MARC region, as land use results in TRIMMS are driven by transit accessibility. See Section 4.2 for a further discussion of land use analyses with TRIMMS.

As expected, transportation pricing has a large impact on the affected population (19.5% VMT reduction) for parking and mileage pricing. There is also a large impact on the affected population for mileage pricing only (9% VMT reduction) with shifts from drive-alone and rideshare to transit, vanpool, cycling and walking.

4. Conclusions and Recommendations

Although each region participated independently in the selection of scenarios and with respect to the available data, there were some common themes and overall comparisons that may be useful to other regions interested in applying TEAM. The options selected in TRIMMS and MOVES for the analysis of scenarios were similar across regions, except for adjustments made based on data availability. This standard analytical approach provides a basis of comparison that is independent of individual strategy performance in each regional context. The lead agencies along with their stakeholders can apply the appropriate regional context for evaluation of the scenario outcomes. Their context and experience drawn from participating in the case studies will inform their view of how best to use the information gathered from this study.

4.1. TEAM Data Requirements

Regional data collection and validation was the most challenging aspect of the analysis. Many factors contributed to the extensive time and interaction that this task involved. MPOs have standard data elements that are used for various routine planning functions, and TEAM was developed to interface with this data without requiring additional data collection or extensive re-evaluation of the information. Every MPO is unique in this regard. The availability of data depends on regional priorities and what data can be collected or borrowed. A strong understanding of both TRIMMS and MOVES allows adjustments to account for these regional data differences; however, some regions may find this challenging.

Data validation is an essential step in the TEAM approach. It is not enough to ensure that the right type of data is used, but also necessary to consider the reasonableness of this data. For instance, the distribution of VMT for transit vehicles among road types is unlikely to be the same as for passenger cars. This study found that the reasonableness of data that may already be in use cannot be taken for granted. A critical element for applying TEAM successfully is the ability to identify questionable data and develop substitutions when needed. In some cases this meant several revised data sets. In other cases it resulted in the extensive use of defaults. Knowledge about the underlying data and previous experience in their use is an advantage.

Use of local data is the best way to ensure that the strategy effectiveness identified through TEAM is applicable to the region. Default data is available in both TRIMMS and MOVES to use when required, but care must be taken to ensure the default data is applicable to the region and to the strategies being evaluated. Regions that undertake a TEAM analysis should allow significant amount of preparation time to identify data requirements, collect or substitute data elements and validate the appropriateness of the data for this type of analysis.

4.2. TRIMMS Support of TEAM

TRIMMS 2.0, which was used for modeling the 2010 national study, was in the process of being updated at the time. TRIMMS 3.0 is the current version and was used for these case studies., A web-based version is now under development. To the extent possible, the new features and functionality in TRIMMS 3.0 were used in an effort to meet the strategy interests of the region. By putting TRIMMS to the test in this way, some potential shortcomings were identified. Many of these issues have been discussed with the TRIMMS developers and in some cases, ways to work within the tool and through post-processing were identified. In a very small number of instances, TRIMMS just might not be the right tool for a selected strategy at this time. The information below is provides some understanding of the more significant issues.

Users of TEAM should be prepared to translate their travel efficiency strategies into TRIMMS-ready inputs. Many of TRIMMS' functions work by manipulation of travel times and travel costs, common factors in travel demand modeling. To model an expansion of HOV lanes in TRIMMS, for example, the user must input changes in typical travel times for carpool trips (and possibly SOV trips). Precise changes would be difficult, if not impossible, to estimate without a detailed transportation network analysis. TRIMMS users can instead rely on assumptions derived from a literature review or expert opinions. For example, in the case studies conducted here, a travel demand modeler at the Boston MPO suggested that a 10% reduction in average carpool times could be reasonably achieved by an expansion of the HOV network in the region. Providing this kind of assumption makes the analysis a goal-based one. Determining what investments must be made to achieve that travel time reduction is not necessary to conduct an exploratory analysis of alternative scenarios.

Land Use

Land use is one of the most critical elements in the evaluation of travel efficiency strategies because it is so central to transportation planning and represents an almost universally identified approach to reducing travel. By shortening distances among travel destinations, increasing mixed use zoning, and concentrating growth around transit nodes, smart growth strategies make walking, cycling, and transit more viable modes of transportation and can even reduce the distances of some car trips. TRIMMS land use features are in an early stage of development, and the predicted impact of land use in these case studies is less than in other current literature. TRIMMS 3.0 includes a new function for estimating the impact of land use strategies, including increasing residential densities, land use mixing, transit station accessibility, and transit-oriented development (TOD). Although this capability was initially viewed as a positive attribute, the TRIMMS land use function raised concerns for two main reasons. First, it is based on a limited data sample. Second, it only considers the propensity of people living in denser areas to increase their use of transit. It does not consider the well-documented effects of increased biking and walking, or shortened trips in private vehicles. As a result, the land use analyses conducted for this study produced smaller VMT reductions in all regions than for the clusters in the 2010 national study used for comparison, where land use impacts were assessed outside of TRIMMS. Land use strategies produced slightly lower impacts than expected in the MassDOT region, and dramatically lower impacts than expected in the PAG and MARC regions. While the underestimation of land use impacts is believed to be a result of the model's response to the availability of transit, (transit availability is much greater in the MassDOT region than in the PAG and MARC regions) more testing is required to determine the cause.

To use the land use functions in TRIMMS 3.0 for a regional analysis, using weighted average densities was determined to be most appropriate. Weighted average population density summarizes regional land use densities in a way that is more representative of residents' daily experience of land use patterns than average density. TAZs with higher populations and which tend to be denser areas, are weighted more heavily than TAZs with lower populations. This approach was used as a pre-processing step in scenario evaluation

There are other approaches to analyzing land use strategies that we recommend for future efforts. The approach used in the 2010 national study with TRIMMS 2.0 (which did not have an explicit land use component) is still valid. In the 2010 study, 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 literature and values included in EPA's Smart Growth Index (SGI) model. It is also possible to use the widely accepted density variable elasticities put forward by Ewing and Cervero.[21] The web-based version of TRIMMS is expected to improve and expand the land use capabilities.

Mode Shifts and Trip Lengths

The 2010 national study identified the importance of trip lengths in determining strategy effectiveness. TEAM is focused on the shift from automobile travel to other modes and to shorter trip lengths. TRIMMS 3.0 does not appear to ensure that trips of equal length are substituted for one another when travel mode shifts. For example, TRIMMS does not account for the fact that a 40 mile vanpool trip replaces a 40 mile car trip. It always applies the average trip length for each mode, which is typically shorter for a car trip than for a vanpool trip. Thus if car trips are replaced with a vanpool trip, the VMT benefit may be affected by the assumption of longer trips.

CUTR has also confirmed that there are no internal controls in TRIMMS to ensure that the number of trips remains constant (or near constant) while trips are shifted between various modes, with the exception of the algorithms used to analyze employer-based TDM strategies.

TRIMMS sometimes shows an increase in rideshare VMT without a commensurate decrease in drive-alone VMT when trip cost values are entered. For modeling HOV lanes (reduction in rideshare travel times), the reduction in SOV VMT is less than the increase in rideshare VMT. This result can be corrected within the TRIMMS model by adjusting elasticities or outside of the model by adjusting the changes in SOV and carpool trips to be more comparable.

In general, the total VMT results are more reliable than VMT by mode. This study presents results for light-duty vehicles only, and therefore does not include bus VMT. TRIMMS tends to over-estimate increases in transit VMT, because it does not allow for increases in transit vehicle occupancy.

There is some interest in strategy types that cannot be evaluated by TRIMMS at the regional scale in its current form. Bike strategies are one consistent example noted. Other interests

[21] Ewing, Reid and Cervero, Robert(2010) 'Travel and the Built Environment', Journal of the American Planning Association, First published on: 11 May 2010 (first)

expressed were park-and-ride, transit fare integration, peak/off-peak fares, transit marketing, public education, and operational improvements such as intelligent transportation system (ITS).

TRIMMS remains the most viable sketch planning tool to support TEAM, and these observations are not intended to detract from its usefulness. The developers at CUTR suggest that improvements to TRIMMS can be supported by users reporting their results and experience using the model.

4.3. MOVES Support of TEAM

MOVES is the best model for estimating emissions for TEAM. It is EPA's current mobile source emission inventory tool, and is required to be used for state and local regulatory analyses, such as for State Implementation Plans (SIP) and transportation conformity determinations.[22] These uses of the model are addressed in other EPA guidance and, although addressing model use for these purposes is beyond the scope of the present analysis, this project has shown that regions are becoming increasingly familiar with its use. Accordingly, many are developing their own, custom MOVES inputs.

Although the inputs developed for those purposes may be used for TEAM, the use of the MOVES model for TEAM differs.[23] Primarily, in a sketch analysis, detailed emission factors are not needed and the additional complexity in producing and using them is not warranted. Instead, as noted previously, overall regional, average emission factors representing the activity-weighted mean of all starting and running activities in the region is produced and coupled with the TRIMMS outputs. These emission factors are calculated as total running emissions from hourly outputs (in grams per year) divided by total running activity (in miles per year) across the modeled region; a similar analysis is made for start emissions. Resulting emission factors are in units of grams of pollutant per average mile driven or grams of pollutant per average start. This is explained further in the TEAM User's Guide[24] and in Section 2.4, above.

A range of technical capability related to the use of MOVES was evident among the regions. There were also some policy questions about the analytical procedures for this study and the regulatory analysis conducted for CAA purposes. Although the same data may often be used, a TEAM analysis cannot be used for emission inventories, air quality demonstrations and transportation conformity determinations required by the CAA. Key topics on the use of MOVES for the case studies are discussed below.

Selection and Use of Base and Future Years

Base and future years in MOVES should be selected to agree with those of the strategies being analyzed. A common issue encountered was that the baseline year selected for the scenario

[22] E.g.,Using MOVES to Prepare Emission Inventories in State Implementation Plans and Transportation Conformity: Technical guidance for MOVES2010, 2010a and 2010b, EPA-420-B-12-028, April 2012

[23] More explanation in the use of this approach is given in: Analyzing Emission Reductions from Travel Efficiency Strategies: A Guide to the TEAM Approach, EPA-420-R-11-025, September 2011.

[24] http://www.epa.gov/otaq/stateresources/policy/420r11025.pdf

analysis was different than the year for which data had previously been prepared in the region, e.g., for a regional emissions analysis. In these cases, the emission inputs for the baseline year were required to be modified (or default values extracted) to agree with the scenario baseline year. The effort needed to adjust for differences in the baseline year should be reduced as more regional data collection and preparation takes place with TEAM analysis in mind.

Data Collection and Validation

Of the three regions, MARC provided the least developed MOVES data. The data MARC provided had been prepared by a consultant for a previous analysis and MARC was not able to collect data beyond this. In some cases, MARC had data, or access to data, but it had not been formatted for or used in any MOVES applications. MARC's data collection also was affected by its regional span across state boundaries, which complicated the efforts.

The Boston region showed the most expertise with MOVES, but a small number of differences between their uses of the model, such as for transportation conformity analyses, and the methods of the TEAM approach had to be considered in this analysis. This is principally related to MassDOT's use of "Emission Rates" calculation type instead of "Inventory" for a single, representative county, and how to translate that parameterization to the TEAM approach documented in Section 3.2. No unique data collection was needed for this TEAM analysis.

Accordingly, CTPS indicated an interest in performing a comparison of the emission factors generated by the TEAM approach to those generated through their emission rate-based approach, since few regions have chosen this approach. Their preliminary comparison showed that the two sets of factors agreed well except for baseline year (2009) NOx running emissions, for which the TEAM values were greater than the curves of values generated by their previous analyses. Subsequent review showed no obvious errors in either analysis and this was noted as an interesting result that should be documented for potential future exploration. It is possible that this was related to removing I/M in the TEAM approach, however this has not been demonstrated conclusively.

The PAG region showed great interest in increasing staff understanding and mastering of MOVES. PAG collected extensive data for this effort and consistently updated their existing data and methods per discussions with EPA. This led to several revisions of input values, but produced one of the most locally specific analyses. In addition, PAG also independently produced their own emission factors. Comparisons of those with the factors generated in this study showed essentially identical results.

It is not clear that any data element was generally less available than others. Instead, the case studies illustrated that the experience level of each MPO and the availability of resources to collect and process data if it was not already in house are factors in the amount of time a TEAM analysis will take. Both of these factors should improve with increasing familiarity with the models and better coordination among various analytical planning efforts by the MPOs.

4.4. Regional Realities and Implications for Using TEAM

Making Assumptions

Using TRIMMS requires agencies to make assumptions about future conditions in terms of inputs that TRIMMS uses, such as trip costs and travel times. These assumptions, especially about a distant future, are not easily made and may represent sensitive issues in the region. Agencies are faced with the decision of how aggressively strategies should be framed simply in the choice of inputs. Stakeholders are not always comfortable coming up with appropriate assumptions or dealing with the types of inputs that TRIMMS uses. For example, transit improvements need assumptions about impacts on access, headways and travel times. Dollar values must be applied to subsidies and pricing. Participating agencies dealt with this requirement differently. Some used it as a way to identify the value of much stronger policies. Others evaluated strategies that would be reasonably feasible in the region. This represents a broad range of approaches and will impact the results of the analysis.

The TEAM approach works best when the considered hypothetical scenario analysis is based on reasonable goals. A stakeholder group composed of well-informed local transportation planners, modelers and land use planners can draft a set of goals for a region based on their professional knowledge and limited additional research. While goals need to be reasonably achievable in the long term, they do not need to be constrained by shorter term political, fiscal, or engineering challenges.

Comparisons and Validations

As discussed in Section 2.3, results for each region were validated against a comparison cluster from the 2010 national study. Clusters were defined by their population size and transit mode shares. These characteristics were used to select a comparison cluster for each of the three case study regions. Results for each strategy were expected to be similar to those from the comparison cluster.

This comparison was used to identify differences in model results that required further examination. Where the case study results were similar to those for the comparison cluster, the case study results were considered to be validated. In some cases it became clear that a selecting a single comparison cluster was not enough to validate results. For example, results for pricing strategies and employer TDM strategies varied broadly from the comparison cluster selected for the MARC region. This difference highlighted that a single cluster may be too limited a comparison. In these cases it was more valuable to compare case study results to the full range of results across all urban clusters. Population size and transit mode share are useful factors to characterize urban regions, but they do not capture other nuances that can affect the results of strategies, such as average trip lengths, travel costs, and geography.

It is also important to consider the affect that the strategy assumptions have on results. Strategies can be specified in more or less aggressive terms, and can be restricted to sub-populations and sub-geographies. These types of variations must be considered when comparing results to those for the 2010 national study.

5. Appendix A: Strategies Identified in the 2010 *Potential Changes in Emissions Due to Improvements in Travel Efficiency* Report

The table below provides the strategy categories for reducing vehicle travel demand selected for analysis:

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

The table below provides detailed descriptions of strategies and the assumptions used in the analysis of scenarios.

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

The table below represents the range of impacts of each TCM on travel activity from the literature. Where elasticity values were available and could be compared, the travel time and travel cost elasticities for each mode used in the 2010 national study fall within the reported ranges shown in Table A-3.

- The ranges provided show estimates of the change in automobile travel or transit ridership for a given change in user travel time or travel cost.
- Where specific elasticities are not available, Table A-3 lists impacts in terms of percentage reductions in travel demand (trips or VMT).
- The elasticities 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.

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

Table A-3. Quantitative Estimates of Travel Activity Impacts of TCMs from Literature	
Examples of Measures	Elasticity/ 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	

6. Appendix B: Emission Change Quantities and Additional Technical Details for the MOVES Analysis

As discussed previously, MOVES was run in inventory mode for each of the regions to produce activity-weighted, average emission factors each the region. These emission factors were coupled with the TRIMMS-predicted changes in activity to produce net emissions changes by scenario for each region. The corresponding relative reductions are presented for each region in the body of the report. Table 18 shows the calculated total emission and travel changes for each of the main pollutants.

Table 18. VMT and Emission Changes by Region and Scenario

Resulting VMT and Emissions Changes for Selected Pollutants (kg), relative to Baseline or BAU Level, by Scenario										
PAG										
Scenario	VMT and Emissions Changes - 2040 BAU to 2040 Scenario					VMT and Emissions Changes - 2010 Baseline to 2040 Scenario				
	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC
Scenario 1: Implement SunTran All Access Pass	-40,970,861	-127,117	-5	-71	-38	21,645,838	5,542,039	81	-12,456	-3,821
Scenario 2: Expand Employer-Based Incentives for Alternative Commute Modes	-40,744,298	-55,843	-2	-33	-21	21,872,402	5,613,313	83	-12,418	-3,804
Scenario 3: Implement BRT on Two Corridors	-40,575,312	-2,148	0	-1	-1	22,041,387	5,667,007	85	-12,387	-3,784
Scenario 4: Expand Parking Pricing in the Downtown-University Corridor	-40,672,387	-33,130	-1	-20	-13	21,944,312	5,636,026	84	-12,405	-3,796
MassDOT										
Scenario	VMT and Emissions Changes - 2035 BAU to 2040 Scenario					VMT and Emissions Changes - 2009 Baseline to 2035 Scenario				
	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC
Scenario 1: Expand Programs and Incentives for Healthy Modes	-103,148,176	-920,323	-48	-598	-283	4,465,026	-8,459,568	-573	-74,147	-29,627

Scenario 2: Expand Programs and Incentives for Healthy Modes + Smart Growth Land Use	-104,237,520	-1,276,754	-66	-830	-393	3,375,683	-8,815,999	-592	-74,378	-29,737
Scenario 3: Expand Programs and Incentives for Healthy Modes + Smart Growth Land Use + HOV Lanes	-104,415,406	-1,334,958	-70	-867	-411	3,197,796	-8,874,203	-595	-74,416	-29,755
Scenario 4: Expand Programs and Incentives for Healthy Modes + Smart Growth Land Use + HOV Lanes + Transit Network Expansion and Improvement	-104,757,958	-1,447,040	-75	-940	-445	2,855,245	-8,986,285	-600	-74,489	-29,789
MARC										
Scenario	VMT and Emissions Changes - 2040 BAU to 2040 Scenario					VMT and Emissions Changes - 2010 Baseline to 2040 Scenario				
	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC	Light-Duty VMT	GHGs (CO2 equivalent)	PM2.5	NOx	VOC
Scenario 1: Expand Ridesharing and TDM programs	-51,104,975	-144,155	-8	-92	-63	12,821,202	-409,306	-410	-33,971	-14,180
Scenario 2: Expand Ridesharing and TDM programs + Transit Improvement and Promotion	-51,824,957	-364,530	-20	-234	-159	12,101,220	-629,681	-422	-34,113	-14,276
Scenario 3: Expand Ridesharing and TDM programs + Transit Improvement and Promotion + Smart Growth Land Use	-51,895,054	-385,975	-21	-248	-169	12,031,123	-651,126	-423	-34,126	-14,286

Scenario 4: Expand Ridesharing and TDM programs + Transit Improvement and Promotion + Smart Growth Land Use + Transportation Pricing	-56,738,678	-1,868,248	-100	-1,200	-820	7,187,499	-2,133,399	-503	-35,079	-14,937

In addition to the four primary pollutants presented here, numerous other pollutants were also included in the analysis as done in the initial study. Table 19 lists the full set of pollutants modeled.

Table 19. Full Pollutant List

Pollutants			
Ammonia (NH3)	Nitrous Acid (HONO)	Primary PM10 - Brakewear Particulate	Primary PM2.5 - Organic Carbon
Atmospheric CO2	Nitrous Oxide (N2O)	Primary PM10 - Elemental Carbon	Primary PM2.5 - Sulfate Particulate
CO2 Equivalent	Non-Methane Hydrocarbons	Primary PM10 - Organic Carbon	Primary PM2.5 - Tirewear Particulate
Carbon Monoxide (CO)	Non-Methane Organic Gases	Primary PM10 - Sulfate Particulate	Sulfur Dioxide (SO2)
Methane (CH4)	Oxides of Nitrogen (NOx)	Primary PM10 - Tirewear Particulate	Total Energy Consumption
Nitrogen Dioxide (NO2)	Primary Exhaust PM10 - Total	Primary PM2.5 - Brakewear Particulate	Total Gaseous Hydrocarbons
Nitrogen Oxide (NO)	Primary Exhaust PM2.5 - Total	Primary PM2.5 - Elemental Carbon	Total Organic Gases
Volatile Organic Compounds			

A variety of MOVES vehicle and fuel types were included in the analysis to characterize the vehicle types used in the TRIMMS model. Those were:

- Diesel Passenger Car
- Diesel Passenger Truck
- Diesel Transit Bus
- Gasoline Light Commercial Truck
- Gasoline Motorcycle
- Gasoline Passenger Car
- Gasoline Passenger Truck
- Gasoline Transit Bus

For the majority of strategies considered here, additional VMT from increased transit ridership is minimal, so transit emissions were excluded. For the PAG region, the influence of pre-aggregation of input data on predictions was briefly considered. Our original approach was designed to use annual aggregation for speed, but EPA cautioned against this because it would compromise accuracy. The comparisons made in Table 20 and Table 21 indicate that the differences in emissions can be significant, although activity differences are very small. Cases where the data uses annual aggregation tend to underestimate annual emissions somewhat relative to hourly inputs (without aggregation). Aggregation has minimal influence on activity. The hourly activity results are within 5% of the yearly results – usually <1% difference. Emissions vary more widely. Hourly results are usually greater than annual results – by an average of 7%, although the range reached 75-85% for buses, especially for off-network activities (starting). In a small number of cases hourly results were seen to be smaller than annual results, by up to 5%.

Table 20. Difference in Activity Values: Hourly-to-Annual Aggregation

	Distance Traveled				Starts
Vehicle	Rural Restricted Access	Rural Unrestricted Access	Urban Restricted Access	Urban Unrestricted Access	Off-Network
Light Commercial Truck	0%	0%	0%	0%	0%
Motorcycle	0%	0%	0%	0%	-3%
Passenger Car	0%	0%	0%	0%	0%
Passenger Truck	0%	0%	0%	0%	1%
Transit Bus	0%	0%	0%	0%	-4%

Table 21. Difference in Emission Values: Hourly-to-Annual Aggregation

Vehicle	Pollutant	Off-Network	Rural Restricted Access	Rural Unrestricted Access	Urban Restricted Access	Urban Unrestricted Access
Light Commercial Truck	Atmos CO2	-10%	-1%	-1%	-1%	-4%
	CO	-11%	-4%	-4%	-4%	-6%
	CO2 Equivalent	-7%	-1%	-1%	-1%	-4%
	Methane (CH4)	-12%	-1%	-1%	-1%	-5%
	N2O	0%	0%	0%	0%	-6%
	NMHC	-8%	-1%	-1%	-1%	-5%
	NOx	-4%	-1%	-2%	-1%	-7%
	PM10 Brakewear		0%	0%	-1%	-6%
	PM10 Elem C	-24%	-1%	-1%	-1%	-3%
	PM10 Organic C	-24%	-17%	-13%	-16%	-13%
	PM10 Sulfate	-11%	-1%	-1%	-1%	-4%
	PM10 Tirewear		0%	0%	0%	-2%
	PM2.5 Brakewear		0%	0%	-1%	-6%

Vehicle	Pollutant	Off-Network	Rural Restricted Access	Rural Unrestricted Access	Urban Restricted Access	Urban Unrestricted Access
	PM2.5 Elem C	-24%	-1%	-1%	-1%	-3%
	PM2.5 Organic C	-24%	-17%	-12%	-16%	-13%
	PM2.5 Sulfate	-11%	-1%	-1%	-1%	-4%
	PM2.5 Tirewear		0%	0%	0%	-2%
	PM2.5 Total Exh	-24%	-7%	-5%	-7%	-8%
	Total Energy	-10%	-1%	-1%	-1%	-4%
	Total Gas HC	-8%	-1%	-1%	-1%	-5%
	VOC	-8%	-1%	-1%	-1%	-5%
Motor-cycle	Atmos CO2	-6%	0%	0%	0%	-1%
	CO	-48%	0%	0%	0%	-1%
	CO2 Equivalent	-6%	0%	0%	0%	-1%
	Methane (CH4)	-24%	0%	0%	0%	-4%
	N2O	3%	0%	0%	0%	-6%
	NMHC	-15%	0%	0%	0%	-4%
	NOx	-30%	0%	0%	0%	1%
	PM10 Brakewear		0%	0%	-1%	-7%
	PM10 Elem C	-29%	-21%	-21%	-21%	-22%
	PM10 Organic C	-29%	-21%	-21%	-21%	-22%
	PM10 Sulfate	-9%	0%	0%	0%	-1%
	PM10 Tirewear		0%	0%	0%	-2%
	PM2.5 Brakewear		0%	0%	-1%	-7%
	PM2.5 Elem C	-29%	-21%	-21%	-21%	-22%
	PM2.5 Organic C	-29%	-21%	-21%	-21%	-22%
	PM2.5 Sulfate	-9%	0%	0%	0%	-1%
	PM2.5 Tirewear		0%	0%	0%	-2%
	PM2.5 Total Exh	-29%	-21%	-21%	-21%	-22%
	Total Energy	-6%	0%	0%	0%	-1%
	Total Gas HC	-17%	0%	0%	0%	-4%
	VOC	-15%	0%	0%	0%	-4%
Passenger Car	Atmos CO2	-10%	-1%	-1%	-1%	-4%
	CO	-29%	-5%	-4%	-4%	-6%
	CO2 Equivalent	-8%	-1%	-1%	-1%	-4%
	Methane (CH4)	-15%	-1%	-1%	-1%	-4%
	N2O	0%	0%	0%	0%	-6%
	NMHC	-13%	-1%	-1%	-1%	-5%
	NOx	-4%	-2%	-2%	-2%	-6%
	PM10 Brakewear		0%	0%	-1%	-6%
	PM10 Elem C	-31%	-19%	-20%	-20%	-22%

Vehicle	Pollutant	Off-Network	Rural Restricted Access	Rural Unrestricted Access	Urban Restricted Access	Urban Unrestricted Access
	PM10 Organic C	-31%	-21%	-21%	-21%	-23%
	PM10 Sulfate	-13%	-1%	-1%	-1%	-4%
	PM10 Tirewear		0%	0%	0%	-2%
	PM2.5 Brakewear		0%	0%	-1%	-6%
	PM2.5 Elem C	-31%	-19%	-19%	-20%	-22%
	PM2.5 Organic C	-31%	-21%	-21%	-21%	-23%
	PM2.5 Sulfate	-13%	-1%	-1%	-1%	-4%
	PM2.5 Tirewear		0%	0%	0%	-2%
	PM2.5 Total Exh	-31%	-20%	-20%	-21%	-23%
	Total Energy	-10%	-1%	-1%	-1%	-4%
	Total Gas HC	-13%	-1%	-1%	-1%	-5%
	VOC	-13%	-1%	-1%	-1%	-5%
Passenger Truck	Atmos CO2	-11%	-1%	-1%	-1%	-4%
	CO	-13%	-4%	-4%	-4%	-6%
	CO2 Equivalent	-8%	-1%	-1%	-1%	-4%
	Methane (CH4)	-12%	-1%	-1%	-1%	-5%
	N2O	-1%	0%	0%	0%	-6%
	NMHC	-8%	-1%	-1%	-1%	-5%
	NOx	-3%	-1%	-2%	-1%	-5%
	PM10 Brakewear		0%	0%	-1%	-6%
	PM10 Elem C	-32%	-6%	-4%	-6%	-7%
	PM10 Organic C	-32%	-20%	-19%	-20%	-20%
	PM10 Sulfate	-13%	-1%	-1%	-1%	-3%
	PM10 Tirewear		0%	0%	0%	-2%
	PM2.5 Brakewear		0%	0%	-1%	-6%
	PM2.5 Elem C	-32%	-5%	-4%	-6%	-6%
	PM2.5 Organic C	-32%	-20%	-19%	-20%	-20%
	PM2.5 Sulfate	-13%	-1%	-1%	-1%	-3%
	PM2.5 Tirewear		0%	0%	0%	-2%
	PM2.5 Total Exh	-32%	-17%	-15%	-17%	-17%
	Total Energy	-11%	-1%	-1%	-1%	-4%
	Total Gas HC	-8%	-1%	-1%	-1%	-5%
	VOC	-8%	-1%	-1%	-1%	-5%
Transit Bus	Atmos CO2	-7%	-1%	-1%	-1%	-3%
	CO	3%	0%	0%	0%	-3%
	CO2 Equivalent	-7%	-1%	-1%	-1%	-3%
	Methane (CH4)	-85%	0%	0%	0%	-4%

Vehicle	Pollutant	Off-Network	Rural Restricted Access	Rural Unrestricted Access	Urban Restricted Access	Urban Unrestricted Access
	N2O	5%	0%	0%	0%	-6%
	NMHC	-74%	0%	0%	0%	-5%
	NOx	-85%	0%	0%	0%	-3%
	PM10 Brakewear		0%	0%	-1%	-6%
	PM10 Elem C	0%	0%	0%	0%	-1%
	PM10 Organic C	0%	0%	0%	-1%	-5%
	PM10 Sulfate	-7%	-1%	-1%	-1%	-3%
	PM10 Tirewear		0%	0%	0%	-2%
	PM2.5 Brakewear		0%	0%	-1%	-6%
	PM2.5 Elem C	1%	0%	0%	0%	-1%
	PM2.5 Organic C	0%	0%	0%	-1%	-5%
	PM2.5 Sulfate	-7%	-1%	-1%	-1%	-3%
	PM2.5 Tirewear		0%	0%	0%	-2%
	PM2.5 Total Exh	0%	0%	0%	0%	-2%
	Total Energy	-7%	-1%	-1%	-1%	-3%
	Total Gas HC	-75%	0%	0%	0%	-5%
	VOC	-74%	0%	0%	0%	-5%

Based on these issues, all MOVES runs for this project were run without pre-aggregation, and hourly outputs from MOVES were manually aggregated to annual.

Another special case involved disaggregating MassDOT provided data. The source populations and total VMTs from MassDOT were cumulative across the seven-county domain. The total VMTs were not allocated to the HPMS vehicle types required by MOVES, so VMT by vehicle type was estimated from MassDOT-provided factors by multiplying the total VMT by the MassDOT-provided allocation factors shown in Table 22.

Table 22. MassDOT VMT allocation factors

HPMS Vehicle Type	Allocation Factor
Motorcycle	0.50%
Passenger Car	51.40%
Passenger Truck/Light Commercial Truck	45.20%
Intercity Bus, Transit Bus, School Bus	0.10%
Refuse Truck, Short-Haul Single Unit, Long-Haul Single Unit, Motorhomes	0.70%
Short-Haul Combination, Long-Haul Combination	2.00%