



Sample Methodologies for Regional Emissions Analysis in Small Urban and Rural Areas

Final Report

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U.S. Department of Transportation

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October 18, 2004

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EXECUTIVE SUMMARY

BACKGROUND AND PURPOSE

The regional emissions analysis is the key analytic component of the transportation conformity process. It is conducted to demonstrate that regional emissions from on-road sources do not exceed levels that could cause or contribute to violations of the health-based air quality standards, and to ensure that transportation plans, programs, and projects are consistent with the State Implementation Plan (SIP) for air quality.

Many small urban and isolated rural nonattainment and maintenance areas face challenges in conducting a regional emissions analysis. Small urban and rural areas typically have limited data on vehicle miles traveled (VMT) and speeds required for emissions analysis. In addition, they often lack network-based travel demand forecasting (TDF) models that predict future travel inputs for emissions analysis. As a result, many small urban and rural areas have faced questions about appropriate methods for conducting a regional emissions analysis.

This document is intended to help small urban and rural areas gain a better understanding of several options for conducting regional emissions analysis. It provides information on sample methodologies and adjustment techniques that have been used for regional emissions analysis in a number of small urban and isolated rural nonattainment and maintenance areas. For each method, the report includes a general description, data sources and procedures, advantages and limitations, and circumstances for which the approach is most appropriate. Although the methodologies profiled in this document are not comprehensive, they provide information that should be helpful to areas in considering potential approaches.

The document is divided into three sections, reflecting key inputs to emissions analysis:

- VMT estimation and forecasting examples (Section 2);
- Speed estimation and forecasting examples (Section 3); and
- Sample techniques for other factors (such as VMT mix by vehicle type, vehicle age distribution, etc.) (Section 4)

This document describes methodologies that have been used in locations without TDF models, as well as techniques that have been used in areas with TDF models. It shows that a wide range of approaches are available to estimate and forecast VMT, speeds, and other factors for emissions analysis. These approaches range from simple to relatively complex methodologies. For example, to predict VMT in an area without a TDF model, identified approaches range from use of a simple linear trend line of historical data to use of more complex regression analyses that employ non-linear functions and take into account factors such as projected population and employment. To estimate speeds, identified approaches range from use of observed speeds to use of speed formulas that are applied to estimate speeds along individual road links. Statewide data are sometimes used (e.g., to develop relationships between VMT on different road types, or to estimate speeds by road type) when data specific to the small urban or isolated rural area are unavailable.

VMT ESTIMATION AND FORECASTING APPROACHES

Section 2 of this report presents several approaches for estimating baseline VMT and for forecasting future VMT, as described below:

Methodologies for Estimating Local Road VMT

Although estimates of VMT are available from the Highway Performance Monitoring System (HPMS), the sample of segments for a small urban or rural area may not be sufficient to provide accurate estimates of VMT by functional roadway classification for an area, particularly for local roadways. Three methods were identified to develop baseline estimates of VMT on local roads given limited data; these methods can be applied in areas with or without a TDF model (since TDF models often do not include lower functional class roadways), and can also be used in forecasts. These methods are as follows:

- Use statewide estimates to calculate the proportion of local road VMT to collector VMT; apply the resulting ratio (Method 1)
- Use available county-level estimates to develop a statistical relationship between local road VMT and collector VMT; apply the resulting formula (Method 2)
- Develop a detailed inventory of local roads, and estimate average daily traffic on local roadways (Method 3)

Methodologies for Forecasting VMT without a TDF Model

Areas without TDF models generally rely on calculations that involve spreadsheets to forecast future VMT. VMT forecasting methodologies range from very simple linear trend lines to more complex non-linear regression analyses. Sample methods include:

- Linear projection of VMT based on estimated growth factor (Method 1)
- Linear projection of total VMT, based on regression analysis of historic VMT data, apportioned by functional roadway class (Method 2)
- Linear projections of VMT by functional roadway class, based on historic VMT data, with adjustments to correct for changes in functional class categories (Method 3)
- Linear projection of interstate VMT based on historic VMT data, and separate population-based forecast for non-interstate VMT (Method 4)
- Analysis of anticipated VMT growth in each interstate corridor, and population-based forecast for non-interstate VMT (Method 5)
- Separate regression forecasts by functional roadway class, based on VMT, population, and employment, with growth factor employing a decay function (Method 6)

Methodologies for Forecasting VMT with a TDF Model

Areas that maintain a TDF model generally use the model outputs to estimate VMT. TDF models offer greater sensitivity to changes in transportation investments or policies, compared to most manual calculation procedures. In estimating future VMT, the TDF model takes into account all transportation improvements at once, predicting the most likely distribution of traffic on the future network. However, adjustments to TDF model outputs are often required in order to make the results suitable for conformity analysis. Adjustments and additions made to the model outputs fall into three categories:

- 1) *Adjustments to TDF model outputs to ensure that VMT results are consistent with estimates used to develop the emissions budget in the SIP.* Samples of these adjustments include:
 - Adjustment factor to scale modeled VMT estimate to HPMS VMT estimate (Adjustment 1)
 - Adjustment to account for trip lengths that do not cover the entire link length in the model (Adjustment 2)
 - Detailed approach to incorporating external trips into a statewide TDF model (Adjustment 3)
 - Use of seasonal adjustment factor (Adjustment 4)
- 2) *Methods to account for local road links that are within the model area but not included within the model network.* Samples of these methods include:
 - Assume percent of modeled VMT (Method 1)
 - Use HPMS estimate of local road VMT and apply VMT growth rate on analogous function class(es) from the model (Method 2)
 - Off-model GIS analysis using traffic analysis zone (TAZ)-level trip data and number of dwelling units (Method 3)
- 3) *Methods to estimate VMT for donut areas not covered by model.* Samples of these methods include:
 - Develop projection of countywide VMT and subtract modeled VMT estimate (Method 1)
 - Use traffic counts and other projections for higher-classification roadways, and apply ratio from model to estimate VMT on lower-classification roadways (Method 2)
 - Use a statewide model and subtract estimates from urban area model (Method 3)

SPEED ESTIMATION AND FORECASTING APPROACHES

Speed estimates are important since emissions rates for VOC, CO, and NO_x can vary widely with speed. Section 3 of the report presents several approaches for estimating speeds without and with a TDF model, as described below:

Methodologies for Estimating Speeds without a TDF Model

Areas without a TDF model generally lack detailed information on the roadway network and associated traffic volumes, and therefore, may not have the option of estimating speed on enough roadway segments to determine the distribution of VMT by speed. In this case, they typically estimate average speed by functional roadway classification. Samples of methodologies used in areas without a TDF model and for donut areas outside of a modeled area include:

- Use observed speeds and/or speed limits (Method 1)
- Use HERS Model at a statewide level (Method 2)
- Use BPR formula or variation (Method 3)
- Use TTI method (Method 4)

Methodologies for Estimating Speeds in Areas with a TDF Model

Estimating Speeds in the Area covered by the TDF Model

A TDF model estimates traffic speed on each link as part of the network assignment process. However, TDF models are typically calibrated so they closely match observed traffic volumes,

not traffic speeds. As a result, the speeds may or may not be accurate for a given area. To account for such inaccuracies, adjustments are sometimes made to TDF model speeds for the purpose of developing emission factors. Samples of methods used include:

- Use TDF model outputs (Method 1)
- Use TDF model outputs with adjustments where model values are inconsistent with observed data (Method 2)
- Use formula and/or lookup tables to estimate speed based on modeled V/C ratio (Method 3)

Estimating Speed in Donut Areas not covered by the TDF Model

In nonattainment or maintenance areas that contain donut areas not covered by a TDF model, the same methods that were presented for areas without a TDF model can be applied to estimate speeds in the donut area. In addition, two other techniques were identified that rely on modeled data:

- Use speeds from modeled area by functional class (Method 1)
- Use speeds from statewide model (Method 2)

OTHER FACTORS

The MOBILE6 model takes into account a number of factors in estimating emissions rates, including the mix of vehicles that contribute to VMT, the age distribution of the vehicle fleet, the mix of VMT by functional roadway classification, and the existence of inspection and maintenance (I/M) programs. While the MOBILE model contains default values for many of these factors, the defaults may not reflect local conditions, and small urban and rural areas may want to use approaches to improve upon defaults. For these factors, Section 4 of the report describes several methods for using local data instead of defaults, and compares these approaches with approaches that rely on default values.

VMT Mix by Vehicle Type

The VMT fleet mix determines how the VMT are assigned to each vehicle type or class. Emission factors across vehicle classes may vary widely. As a result of this variation, small changes in fleet mix have the potential for large changes in emission totals. Sample approaches for estimating VMT mix by vehicle type include:

- Use MOBILE6 model default, which is based on national-level vehicle registration data and projected future changes in registrations (Method 1)
- Use available local data (vehicle registration data, traffic data, or combination) and assume constant mix (Method 2)
- Use available local data for base year fleet mix and iteratively adjust to reflect expected changes in mix (Method 3)

Vehicle age Distribution

The vehicle age distribution determines the fraction of vehicles operating within each emission control requirement standard and the deterioration of the emission control technology. Emission rates vary significantly with vehicle age, and thus, small changes in fleet age may result in large changes in emission totals. Sample approaches to vehicle age distribution include:

- Use MOBILE6 model default, which is based on national-level vehicle registration data (Method 1)
- Use local vehicle registration data for in-use fleet (Method 2)

Percent of VMT on Freeway Ramps

The MOBILE6 model develops emissions factors for four sets of driving cycles: freeway (excluding ramps), arterial/collector, local roadway, and freeway ramp. Most transportation agencies do not collect estimates of VMT on freeway ramps, and so the MOBILE model includes a national default of 8 percent of freeway VMT occurring on freeway ramps. Although EPA generally recommends using the default, this national average may not be appropriate for rural areas with a limited number of interchanges and some small urban areas. The report describes one method that involves a local traffic survey to collect data on the percentage of freeway VMT on ramps.

Inspection and Maintenance Program Implementation

I/M programs reduce average emissions rates, and the type of I/M program may have potentially significant impacts on emission totals. The standard way to address I/M programs in MOBILE6 is to specify the I/M programs in place in the nonattainment or maintenance area. However, this approach may not be accurate in small urban or rural areas that are not subject to I/M requirements but have a sufficient amount of through traffic from areas that are subject to I/M requirements. These “through vehicles” can significantly affect on-road emission rates. Sample approaches for addressing I/M programs include:

- Apply type of I/M program to area of analysis (standard approach) (Method 1)
- Use local data sources to estimate proportion of traffic subject to I/M (Method 2)

SELECTING AN APPROPRIATE APPROACH

In selecting an appropriate approach, there are often tradeoffs to be made. Simple methods tend to have advantages in terms of data availability and ease of application, but may not be as technically robust. In contrast, more complex methods tend to have advantages in terms of being able to produce robust results for different circumstances and being sensitive to changes in transportation investments and other policies, but may be more time-consuming to apply and require greater investments in data collection.

The advantages and limitations of each approach need to be weighed in terms of the availability of data and local understanding of conditions that influence the accuracy of an approach. Although complex methods may be more robust overall, simple methods may be most appropriate in cases where results are expected to be similar to those of a more complex method with less data collection and cost.

The unique circumstances of the nonattainment or maintenance area should determine what techniques or approaches are most appropriate. For example, a linear projection of VMT may be appropriate if historical population trends are expected to continue and the road network is expected to remain largely the same; however, it would not be as appropriate if the area is expecting much more rapid or slow growth than in the past, or if a major new highway facility is planned, which could bring in more through traffic. If MOBILE defaults are being considered, it is important to examine whether the defaults reflect patterns for the area of analysis or whether

the defaults reflect areas that are different in character. Similarly, if state-level data are being considered when local data are unavailable (for example, to estimate the proportion of VMT on local roads to collectors, or to estimate average speeds by roadway type), it is important to consider whether the area of analysis exhibits characteristics typical of the state as a whole.

There is no “one-size fits all” approach for conducting an appropriate regional emissions analysis. Methods should be selected based on data availability and local conditions, and should be determined through the interagency consultation process. This report seeks to support current and newly designated areas subject to conformity in considering potential options for regional emissions analysis.

1 INTRODUCTION

1.1 BACKGROUND AND PURPOSE

The regional emissions analysis is the key analytic component of the transportation conformity process, and is conducted to demonstrate that transportation plans, Transportation Improvement Programs (TIPs), and projects are in conformity with the State Implementation Plan (SIP) for air quality. A critical factor that will influence what methods can be used for the regional emissions analysis is whether or not the region has a travel demand forecasting (TDF) model. The transportation conformity rule specifically requires that serious and above ozone and carbon monoxide nonattainment areas with urban population more than 200,000 use network-based travel models for the regional emissions analysis. For small urban and rural areas, and others not meeting these criteria, the conformity rule allows areas flexibility to conduct regional emissions analysis by either continuing the existing modeling practices of the MPO or by using “any appropriate methods” that account for vehicle miles traveled (VMT) growth and future transportation policies.

Many small urban and rural nonattainment and maintenance areas face challenges in conducting the regional emissions analysis. These areas often do not have TDF models to generate travel outputs required for use in emissions analysis. They also often have very limited data on VMT and speeds required for emissions analysis. As a result, existing small urban and rural areas have faced questions about what are appropriate methods for conducting a regional emissions analysis given limited data and tools.

The purpose of this document is to provide information on methodologies and adjustment techniques that have been used for regional emissions analysis in several small urban and isolated rural nonattainment and maintenance areas. The methodologies described in this document were identified through a research effort that involved a literature review and contacts with staff from over twenty State Departments of Transportation (DOTs) and metropolitan planning organizations (MPOs) that conduct conformity analysis. This document describes and assesses methodologies, and is intended to help small urban and rural areas gain a better understanding of some of the procedures that have been used for conducting regional emissions analysis.

1.2 HOW TO USE THIS DOCUMENT

This document is designed as a “menu” of methodologies and adjustment techniques that can be used in small urban and rural areas for regional emissions analysis. An important theme behind this document is that a variety of methods are available and appropriate for different circumstances. This document is not intended to direct a specific methodology to be used in a particular location. The methodology that is ultimately used should be determined through the interagency consultation process, and should reflect considerations appropriate for the nonattainment or maintenance area. The methodologies profiled in this document are not necessarily comprehensive; other methods may be feasible or appropriate.

The document is organized as follows:

Sections for Key Inputs Required for Emissions Analysis

The document is divided into three main sections, which relate to specific inputs required for conducting the regional emissions analysis:

- **VMT Estimation and Forecasting Examples (Section 2)**– VMT estimates (by functional roadway classification and speed are a necessary input for estimating regional emissions, and are required for each year being analyzed. VMT estimates are used together with emissions factors developed from EPA’s MOBILE model (or EMFAC in California) to estimate emissions.¹ This section describes methods for developing estimates of VMT for use in the emissions analysis.
- **Speed Estimation and Forecasting Examples (Section 3)**– Speed is a key input required in order to estimate emissions factors in EPA’s MOBILE Model (and EMFAC). This section describes methods for developing estimates of average speeds, or speed distributions, for use in the emissions analysis.
- **Other Factors: Sample Techniques (Section 4)** – The emissions rates generated by MOBILE (and EMFAC) depend on a number of factors, including the VMT mix by vehicle type, vehicle age distribution, and the participation of vehicles in inspection and maintenance (I/M) programs. The MOBILE model provides default values for these factors, which are often used in small urban and rural areas. This section summarizes methods that can be used to generate these factors using local data in place of defaults.

A typical user of the document should review methods within each of these three sections since each addresses a necessary component of the emissions analysis process. Moreover, how VMT is treated will have impacts on how speeds must be treated.

Section 5 of the report contains a summary, and Section 6 provides resources for additional information on regional emissions analysis and the conformity process.

Areas with Travel Demand Forecasting Models

Although not required to use TDF models, many small urban areas do have TDF models, and use them to conduct conformity analysis. A number of States have also developed statewide TDF models (e.g., Maine, Michigan, Oregon), which are used to estimate VMT for higher-order roadway classifications. The methodologies that can be used in these areas to forecast VMT and speeds will differ considerably from those in areas without models. As such VMT and speed methodologies are addressed separately for areas with and without TDF models. In cases where a TDF model is available, techniques are often used to adjust the outputs of the models to reflect local conditions and to ensure that the results can be used appropriately for emissions analysis. In addition, methods are sometimes needed to address “donut” areas² or specific functional roadway classifications that are not addressed by the TDF model.

¹ In California, emissions factors are developed through the EMFAC model rather than through MOBILE. Although the MOBILE model is referred to through this report, many of the same methodologies can also be applied in developing inputs to EMFAC.

² A donut area is a geographic area that falls within the boundary of a nonattainment or maintenance area that contains a metropolitan area, but falls outside of the metropolitan planning area boundary. Emissions

The typical user of this document can skip to the appropriate subsections of the document depending on whether or not a TDF model is available.

Methodology Descriptions

Each methodology is presented in a standard format for easy reference. For each methodology, the document briefly describes the method, discusses where the method is most applicable, and provides information on advantages and limitations of the approach, based on ICF Consulting's assessment. It also identifies a sample location where the methodology has been applied.³

Each method is assessed on a qualitative scale (from low to high) across four criteria, in order to help the user determine the applicability of each:

- **Availability of Data** – How readily available are the data that are required in order to use the method? Methodologies that require limited amounts of readily available data will score “high”, while those that require a large amount of data that may be difficult to obtain will score “low”.
- **Ease of Application** – How simple or complex is the method to actually apply? Methodologies that are relatively easy to implement and have relatively simple procedures or calculations will score “high”, while those that require a great deal of time, effort, and resources to apply will score “low”.
- **Technical Robustness** – How reasonable are the results of the methodology believed to be for a variety of different circumstances? Methodologies that take into account a full range of factors that might affect emissions will score “high”, while those that use a lot of simplifying assumptions and whose results do not vary in different circumstances will score “low”.
- **Policy Sensitivity** – How sensitive are the results of the methodology to changes in highway investments, transit investments, or other policies? Methodologies that take into account the effect of transportation decisions will score “high” (e.g., a VMT methodology that predicts lower VMT based on increased transit investments and associated transit service improvements would exhibit high policy sensitivity). In contrast, methods that predict the same results regardless of relevant policy changes will score “low” (e.g., speed tables that predict the same speed for traffic regardless of a large investment in a major corridor signal coordination project would exhibit low policy sensitivity).

It is important to point out that simply because a methodology scores “low” on technical robustness or policy sensitivity does not mean that the methodology is inferior or should be avoided. In some cases, a relatively simple methodology may be the most appropriate, and it may not be worth the additional effort or cost to use a more complex methodology if the results are

in donut areas in most cases must be included in the metropolitan area regional emissions analysis for the Plan and TIP.

³ It should be noted that EPA's MOBILE6 model is currently required for use in conformity analysis for all states outside of California. Several of the methodologies identified through this research were applied using previous versions of EPA's MOBILE model, EPA's PART5 model to estimate particulate matter, or the EMFAC model in California. These methodology descriptions, in some cases, have been adapted slightly to reflect procedures that could be applied using MOBILE6.

not expected to be substantially different. The specific circumstances in the region will determine which approaches are most appropriate.

2 VMT ESTIMATION AND FORECASTING EXAMPLES

2.1 BACKGROUND – IMPORTANCE OF VMT ESTIMATES

The basic process for calculating emissions involves multiplying VMT by a per-mile emission factor. Thus, accurate VMT forecasts are extremely important for developing emissions estimates in the conformity analysis. This section focuses on the methodologies and approaches used for estimating baseline VMT and forecasting future VMT.

Clearly, any methodology to forecast future VMT requires an accurate estimate of current VMT (and often historic VMT and socio-economic factors as well). Data from the Highway Performance Monitoring System (HPMS) are typically used in small urban and rural areas to estimate VMT for the current year.⁴ However, the accuracy of HPMS-based estimates may be limited in small urban and rural areas and for local roadways in particular (as opposed to arterials and other higher functional classifications), given the sparse sample sizes at the county level. As a result, some areas have developed detailed inventories of local road mileage and supplemented the HPMS sample with additional traffic counts, and some have developed detailed traffic monitoring systems in order to develop more accurate estimates of VMT at the county level.

A basic process for estimating VMT using a sample of traffic count data for use in emissions analysis is as follows:⁵

1. Calculate the sum of counts in each facility type
2. Determine the sample size in each facility type (i.e., the number of count sites)
3. Determine the average volume for a facility type by dividing total count by sample size
4. Obtain total centerline miles of each facility type in the modeling domain
5. Multiply average volume by the number of centerline miles for each facility type to estimate total VMT for each facility type.

VMT estimates are used together with per mile emissions factors developed using the EPA MOBILE6 model (or EMFAC in California), which in turn, are dependent on speed estimates. As a result, the level of detail in the estimation of VMT will influence the level of detail that can be used in the estimation of speeds, and will ultimately affect the regional emissions estimates.

VMT estimates are typically developed on a daily basis, for multi-hour time periods, or by hour:

- 1) **Average daily VMT** – The simplest approach is to develop estimates of average daily VMT by functional roadway classification. Areas with TDF models use modeled

⁴ The HPMS provides data that reflects the extent, condition, performance, use, and operating characteristics of the nation's highways. For more information on background, scope, major uses of the HPMS, and reporting requirements, consult FHWA's HPMS Field Manual at <http://www.fhwa.dot.gov/ohim/hpmsmanl/hpms.htm>.

⁵ Adapted from *Guidance for the Development of Facility Type VMT and Speed Distributions*, U.S. EPA, Report Number M6.SP.D.004, February 1999.

volumes by roadway segment. Areas that do not have a TDF model usually rely on HPMS estimates of VMT by functional roadway classification.

- 2) **VMT for different periods of the day** – This approach involves developing estimates of VMT for different periods of the day (e.g., AM peak, PM peak, off-peak). This approach is commonly used in areas where there is significant traffic congestion during peak hours. In areas with a TDF model, the model usually can be run to estimate VMT for the morning and evening peak periods, and for total average daily traffic, in which case, the peak periods can be subtracted from the daily total in order to estimate off-peak VMT. Otherwise, average daily traffic estimates can be disaggregated to time periods using locally-developed factors. In areas without a TDF model, average daily traffic is often distributed between peak periods and off-peak periods based on local factors developed from traffic counts.
- 3) **VMT by hour of day** – The most detailed breakdown of VMT can be developed by subdividing estimates of daily VMT or VMT by time period to generate hourly VMT. This hourly breakdown is often based on estimates of hourly volumes from a sample of roadways and average roadway speeds each hour. These sample results provide an estimate of VMT for each of 24 hours in the day. This step allows for a more detailed speed analysis in MOBILE6, which allows VMT to be distributed by hour of the day and by speed category or “bin.”

In many small urban and rural areas, a simple analysis of average daily traffic will suffice for the regional emissions analysis. However, it is important to recognize cases where a more detailed breakdown is useful to reflect local conditions that could significantly influence emissions.

Moreover, although many areas use annual average daily VMT (based on estimates of annual average daily traffic, or AADT, on roadways), a seasonal adjustment is sometimes applied so the resulting VMT used in the conformity analysis reflects either an average summer or winter weekday, depending on the pollutant of concern (summer for ozone, winter for CO). This seasonal adjustment is most important in areas with large seasonal variations in traffic patterns, and is more often applied in areas that have regional TDF models.

2.2 MOBILE6 REQUIREMENTS FOR VMT

MOBILE6 differs from previous versions of the MOBILE emissions model in that it produces different emission factors for different roadway facility types. The four facility types are:

- Freeways
- Arterials and collectors
- Local roads
- Freeway ramps

Using the VMT BY FACILITY command, the user can input the fraction of VMT that occurs on each facility type. The user can run the model assuming 100 percent for a specific facility type in order to develop facility-specific emission factors, or can input a fractional value for each facility in order to develop a composite emissions factor across all road types.

As noted above, MOBILE6 allows users to input VMT information at different levels of detail, depending on the availability of local data. MOBILE6 allows users to specify the distribution of VMT by hour of the day, by speed, and by vehicle type.⁶ Using the VMT BY HOUR command in MOBILE6, the user can input the fraction of VMT that occurs at each hour of the day (24 fractional values). The 24 fractions should sum to 1. If this command or other MOBILE6 commands that allow specification of VMT by hour are not used, then MOBILE6 will use national default data for the distribution of VMT by hour.

⁶ Methods for estimating VMT by speed bin are discussed in Section 3. Methods for estimating VMT mix by vehicle type are discussed in Section 4.2.

2.3 METHODOLOGIES FOR ESTIMATING LOCAL ROAD VMT

The MOBILE6 model requires the user to specify VMT for four road categories: freeways (not including ramps), arterials/collectors, local roadways, and freeway ramps. In small urban and rural areas, the HPMS estimate of VMT on lower classification roadways, particularly local roadways, is generally not very reliable, given the small sample in the area. In some cases, regions may not even have a reliable estimate of total road mileage of local roadways. As a result, several methodologies can be employed to develop improved estimates of local road VMT for the baseline year. These methods can also be applied to develop projections of future VMT.

Samples of these methodologies profiled in this report include:

- Method 1: Use statewide data, which is more statistically significant than county-level HPMS data in order to develop a ratio between local roadway VMT and collector VMT; apply this ratio to develop an estimate of local roadway VMT
- Method 2: Conduct a statistical analysis of the relationship between VMT on local roadways and VMT on collectors using available state or county-level estimates, in order to develop a formula to calculate county-level VMT on local roads
- Method 3: Develop a detailed inventory of all local roads, and conduct additional traffic counts or make assumptions about average daily traffic in order to develop an estimate of baseline local roadway VMT

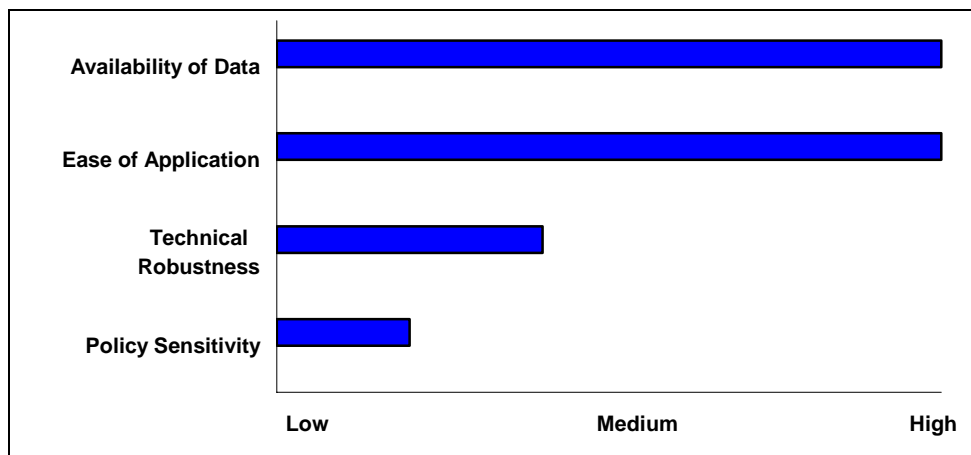
These methodologies can be used both in areas with or without a TDF model, since TDF models generally do not include road links for local roadways.

For purposes of emissions modeling, note that the assignment of VMT as “local road” VMT may not match with the standard highway classifications of urban local roads and rural local roads. In MOBILE6, local roads are defined as facilities having extremely low average speeds and frequent stops at intersections. They generally represent roads in residential areas and are characterized by having no traffic lights, no more than one lane in each direction, vehicle parking on the street, and traffic control handled via stop/yield signs. MOBILE6 assumes an average speed of 12.9 miles per hour for local roads, which cannot be changed by the user. As a result, roadways that fit within FHWA’s “rural local roadways” and “urban local roadways” functional classifications with higher average speeds should be considered arterials/ collectors in MOBILE6. Rural local roadways as defined by FHWA will generally not fit the MOBILE6 definition of local roadways, and many urban local roads will also not fit the definition. Given these differences in definitions, it is important for the analyst to develop an accurate estimate of total VMT in the nonattainment or maintenance area, and to pay special attention to classifying the VMT appropriately into the MOBILE6 road classifications.⁷

⁷ The MOBILE6 emissions model functions differently than MOBILE5, which simply developed emission factors based on average speeds. As a result, methodologies for conformity analysis using MOBILE5 did not need to make this distinction between the different definitions of local roadways, and commonly developed emissions estimates based on average speed by functional roadway classification.

ESTIMATING LOCAL ROAD VMT

Method 1: Use Statewide Estimates to Calculate Proportion of Local Road VMT to Collector VMT



Description State-level data on VMT on local roads and collectors is used in order to develop a ratio of local road VMT to collector VMT on urban and rural functional road classifications. This ratio is then applied to county-level estimates of VMT on collectors.

Method Applicability This method is most appropriate when the region being examined is expected to have relatively similar patterns as the State as a whole. This method is broadly applicable to virtually all small urban and rural areas with limited data on local roadway VMT.

Data Sources and Procedures *VMT Estimation and Forecasting*
VMT estimates for local roadways in a particular county are developed by multiplying the HPMS estimates of VMT on collectors in the county by the ratio of local roadway VMT to collector VMT developed using HPMS data at the statewide level (see equation below).

$$CountyVMT_{local} = CountyVMT_{Collector} \times \frac{StateVMT_{local}}{StateVMT_{collector}}$$

The equation is applied separately for rural local roads, using the proportion of statewide VMT on rural local roads to rural collectors, and for urban local roads, using the proportion of statewide VMT on urban local roads to urban collectors. The estimates of VMT are believed to be more accurate at the statewide level than at the county level, given the limited HPMS sample size at the county level. The same procedure can also be applied using ratios developed at a smaller geographic level than the state (for example, a set of counties within a large state), if sufficient data are available.

This procedure may be used to develop a base year estimate of VMT on local roadways or to forecast VMT on local roadways given a forecast of VMT on collectors.

- Advantages**
- Simplicity of the approach.
 - Resource requirements are very small.
 - Rationale and data sources are generally accepted.
- Limitations**
- Methodology may not reflect differences in patterns between the county under consideration and the state (for example, if there is a much smaller local road network proportional to collectors).

Example Location This approach had been used in Kentucky for rural areas and small urban areas (however, this approach is not currently used). In its original approach, the Kentucky Transportation Cabinet (KYTC) examined the statewide ratio of VMT on local roads and collectors, and used the following ratios to predict local road travel in each county: 0.33 (rural local/rural collector), 0.28 (urban local/urban collector in urbanized counties), 0.12 (urban local/urban collector in non-urbanized counties).

Website: http://transportation.ky.gov/Multimodal/Air_Quality.asp

References:

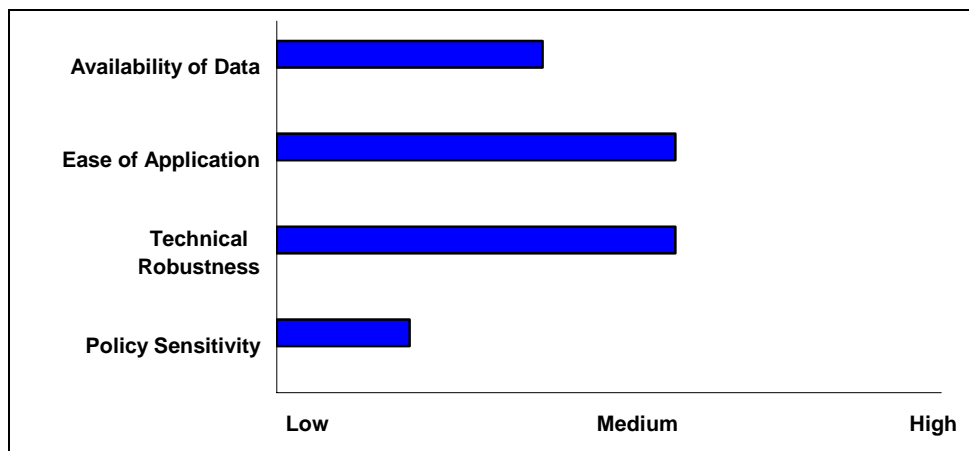
M.L. Barrett, R.C. Graves, D.L. Allen, J.G. Pigman, G. Abu-Lebdeh, L. Aultman-Hall, S.T. Bowling, Analysis of Traffic Growth Rates, University of Kentucky Transportation Center, August 2001.

Bostrom, Rob and Jesse Mayes, "Highway Speed Estimation for MOBILE6 in Kentucky," Kentucky Transportation Cabinet, 2002.

Excel Spreadsheet tables, "2001-2030 VMT Tables," supplied by Jesse Mayes, Kentucky Transportation Cabinet.

ESTIMATING LOCAL ROAD VMT

Method 2: Develop Statistical Relationship between Local Road VMT and Collector VMT



Description This methodology is similar to Method #1, but uses several data points in order to develop a formula relating local road VMT to collector VMT. It relies on several samples of local and collector VMT (e.g., county-level estimates, for various years).

Method Applicability This method is applicable to virtually all small urban and rural areas with limited data on local roadway VMT for the nonattainment or maintenance area. It requires, however, sufficient data on local and collector VMT from several samples of counties in order to conduct the statistical analysis.

Data Sources and Procedures *VMT Estimation and Forecasting*
An analysis is conducted using available state-level HPMS estimates or county-level samples in order to relate VMT for local roads with VMT for collectors. The analysis can be conducted by testing various equations to describe the relationship between local road and collector road volumes and selecting the best fitting equation. For example, a typical spreadsheet package can test the following:

Simple linear equation⁸: $LocalADT = a \times CollectorADT + b$

Logarithmic equation: $LocalADT = a \times \ln(CollectorADT) + b$

Exponential equation: $LocalADT = a \times e^{b \times CollectorADT}$

Power equation: $LocalADT = a \times CollectorADT^b$

In all cases, *a* and *b* are constants that are determined based on the relationship of existing local and collector VMT data.

The formula that is developed from this analysis can then be used to develop an estimate of county-level VMT on local roads given an estimate of county-level VMT on collectors. The formula can be used both for the baseline analysis and projections.

⁸ This formula is nearly equivalent to method 1, except that it allows for a certain baseline VMT level on local roads that is independent of the volume on collector roads.

- Advantages**
- Relative simplicity of the approach.
 - Rationale and data sources are generally accepted.
- Limitations**
- Requires several estimates of local and collector VMT at a county level, drawn from more detailed sampling and traffic counts on roadways.
 - Methodology may not reflect conditions that are particular to the county under consideration that may make the relationship between different functional roadway class traffic volumes different from other parts of the state (for example, if there is a much smaller local road network proportional to collectors).
 - Methodology may not substantially improve upon estimates using a simple ratio of local road VMT to collector VMT.

Example Location The approach has been used by the Kentucky Transportation Cabinet (KYTC) for small urban and rural areas in order to improve estimates of local road VMT previously developed using Method #1. KYTC used GPS technology to develop accurate mileage data from local roadways statewide. Reasonably good ADT data at the county level were available from HPMS down to the collector functional class.

Research conducted by the University of Kentucky Transportation Center (see first reference below) found that a simple ratio of local road to collector VMT was inadequate to predict local road VMT. Researchers graphed local ADT against collector ADT to develop the best fitting relationship between these two measures. For Kentucky, they arrived at the following equation:

$$\text{Local ADT} = 3.3439 \times (\text{Collector ADT})^{0.6248}$$

KYTC selected to use this equation rather than a simple ratio since they found that local roads carry much less traffic relative to collectors in locations where collectors have higher VMT. Therefore, if a simple ratio had been used as in method #1, then local road VMT would have been overestimated where collector VMT was relatively high.

Website: http://transportation.ky.gov/Multimodal/Air_Quality.asp

References:

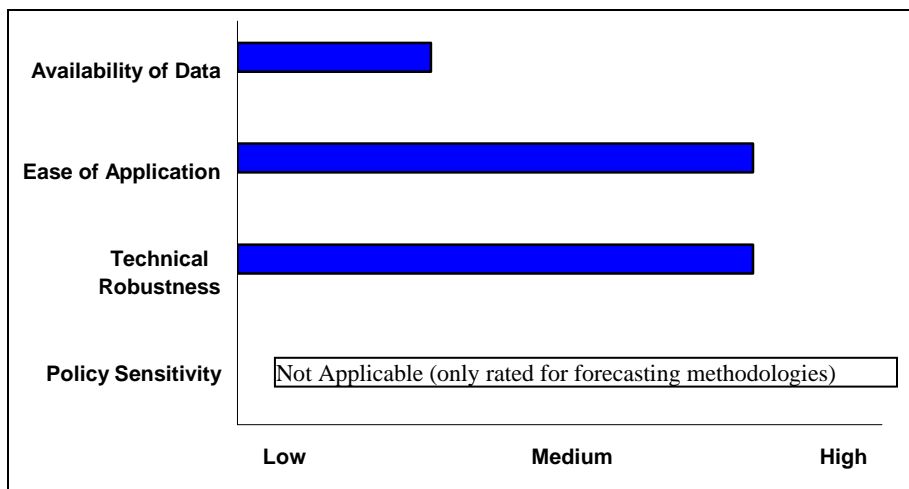
M.L. Barrett, R.C. Graves, D.L. Allen, J.G. Pigman, G. Abu-Lebdeh, L. Aultman-Hall, S.T. Bowling, Analysis of Traffic Growth Rates, University of Kentucky Transportation Center, August 2001.

Bostrom, Rob and Jesse Mayes, "Highway Speed Estimation for MOBILE6 in Kentucky," Kentucky Transportation Cabinet, 2002.

Excel Spreadsheet tables, "2001-2030 VMT Tables," supplied by Jesse Mayes, Kentucky Transportation Cabinet.

ESTIMATING LOCAL ROAD VMT

Method 3: Estimate Average Daily Traffic on Inventory of Local Roadways



* Note: This method is used solely to develop an estimate of baseline VMT for local roadways, with or without a TDF model. Projections can be made using any of the methods described in Sections 2.4 or 2.5, depending on whether a TDF model is available; a very simple approach is to estimate and apply a growth factor.

Description This approach involves developing an inventory of all local roadways in the county of interest. Data on average daily traffic (ADT) on individual road links, based on traffic counts, are then applied to the roadway mileage. For links where there are no data, the ADT from other roadways or a default ADT assumption can be applied.

Method Applicability This method is broadly applicable to virtually all small urban and rural areas. It is most appropriate when the region being examined is expected to have different patterns from the state as a whole and if local roadways make up a disproportionately large share of total traffic.

Data Sources and Procedures *VMT Estimation*
A detailed inventory of total road mileage on local roadways is required. Traffic counts are conducted in order to develop estimates of average daily traffic (ADT) on a sample of local roadways in the area of interest. The ADT estimates are then applied to the appropriate road links or assumed to apply to other nearby links. Alternatively, an overall average ADT can be applied across all road mileage. VMT is estimated by multiplying ADT by the link length.

Advantages

- Accounts for actual road mileage of local roadways in the area of interest.
- Use of traffic counts provides better indication of actual traffic levels in the county of interest as opposed to using statewide data.
- Level of data collection can vary, and should depend on whether there is great variation in traffic volumes on local roadways.

Limitations

- Methodology requires additional data collection compared to those that rely on statewide data.
- Assumptions of ADT may not be accurate for all roadways.
- Additional resources and complexity are introduced in the analysis if local road

links are examined at a detailed level.

Example Location North Carolina DOT (NCDOT) applied this methodology in conducting analyses of regional emissions in donut areas outside of MPO boundaries. NCDOT records AADT for all roads in all functional classifications. Since less than 74 percent of local road mileage was covered by actual counts, for local road links without traffic counts, NCDOT assumed 400 ADT. This is the maximum amount of traffic expected on low-volume local roads.⁹

The Rogue Valley MPO in Medford-Ashland (Klamath County), Oregon, used an assumption of 20 ADT on unpaved roads in the base year as part of its conformity analysis for the 2004-2007 Transportation Improvement Program (TIP). The ADT average was developed by the Oregon Department of Transportation's Transportation Planning and Analysis Unit. The MPO assumed a growth rate of 1.2 percent per year for future projections.

References:

North Carolina DOT, Davidson County, and the North Carolina Department of Environment, "Emissions Analysis Report for the Transportation Plan for the Rural Portion of Davidson County." September 27, 2002.

Rogue Valley MPO, "2004-2007 Transportation Improvement Program and Air Quality Conformity Determination," August 26, 2003.

⁹ American Association of State Highway and Transportation Officials, *A Policy on the Design of Highways and Streets [2001 Greenbook]*, 2001.

2.4 METHODOLOGIES FOR FORECASTING VMT WITHOUT A TDF MODEL

Areas without TDF models generally rely upon calculations that involve spreadsheets or other tools to forecast future VMT. Six methodologies for projecting VMT are identified here, ranging from a very simple linear trend-line projection to use of more complex regression analyses that base VMT forecasts on a range of demographic and economic factors.

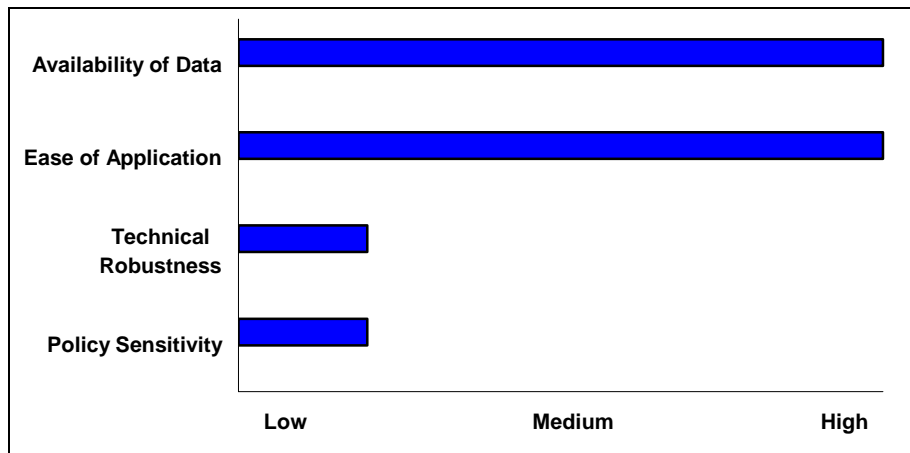
Sample methods include:

- Method 1: Linear projection of VMT based on estimated growth factor;
- Method 2: Linear projection of total VMT, based on regression analysis of historic VMT data, apportioned by functional roadway class;
- Method 3: Linear projections of VMT by functional roadway class, based on historic VMT data, with adjustments to correct for changes in functional class categories;
- Method 4: Linear projection of interstate VMT based on historic VMT data, and separate population-based forecast for non-interstate VMT;
- Method 5: Analysis of anticipated VMT growth in each interstate corridor, and population-based forecast for non-interstate VMT; and
- Method 6: Separate regression forecasts by functional roadway class, based on VMT, population, and employment, with growth factor employing a decay function.

It should be noted that although these methodologies all rate relatively low in terms of policy sensitivity (their ability to respond to changes in highway investments, transit investments, or other policies), separate analyses can be conducted in order to evaluate the effects of new transportation investments, including highway facilities, transit services, park and ride lots, and other transportation control measures. Small urban and rural areas often conduct special analyses of these types of investments to assess the effect to which they might be expected to bring in additional “through” traffic, change the routes that drivers take, or shift drivers from motor vehicles to transit or higher occupancy modes. The effects of these investments on VMT is then added to or subtracted from the totals resulting from the general VMT projection methods.

FORECASTING VMT WITHOUT A TDF MODEL

Method 1: Linear Projection of VMT based on Estimated Growth Factor



Description Total VMT is projected to the future based on an estimated growth rate developed by planners. This growth rate may reflect historical growth, expectations for future growth using demographic or economic projections, or other factors as appropriate.

Method Applicability This method is broadly applicable to virtually all areas without TDF models. It is most appropriate when there are extremely limited resources for forecasting VMT, or when future growth rates are not expected to follow historical patterns.

Data Sources and Procedures *VMT Projection*
VMT projections are developed by applying an estimated VMT growth rate to a base-year estimate of VMT, developed from traffic counts and data on roadway extent. Regional planners develop the VMT growth rate based on historical information or expectations for future growth using demographic or other projections. Projected VMT is then apportioned to the functional classes in the same ratio as the most recent year of VMT data.

Advantages

- Simplicity of the approach.
- Resource requirements are very small.

Limitations

- Methodology may not reflect future changes in factors that will influence VMT growth, such as population growth, economic growth, land use changes, and major new developments.
- Methodology does not reflect potential differences in travel growth rates on different types of roadways.
- Methodology is not sensitive to expected changes in transportation investments or policies. Any additional traffic growth associated with new facilities will need to be analyzed separately. Upgrades of facilities to higher classifications will not be reflected.

Example Location Colorado DOT used this approach in one conformity analysis conducted in Aspen, a rural nonattainment area for PM-10. The VMT forecast was based on a baseline estimate of VMT for 1990 from vehicle counts, projected to future years based on an estimated growth rate of 2 percent per year. This overall growth rate was estimated by City of Aspen planners based on experience with recent trends and anticipated growth patterns.

This approach can also be applied for a particular type of roadway (i.e., local roadways, unpaved roads) when a model does not address the roadway class. For instance, the Rogue Valley MPO in Medford-Ashland (Klamath County), Oregon, assumed a growth rate of 1.2 percent per year for future projections of VMT on unpaved roads as part of its conformity analysis for the 2004-2007 Transportation Improvement Program (TIP).

Website:

<http://www.dot.state.co.us/environmental/CulturalResources/AirQuality.asp>

References:

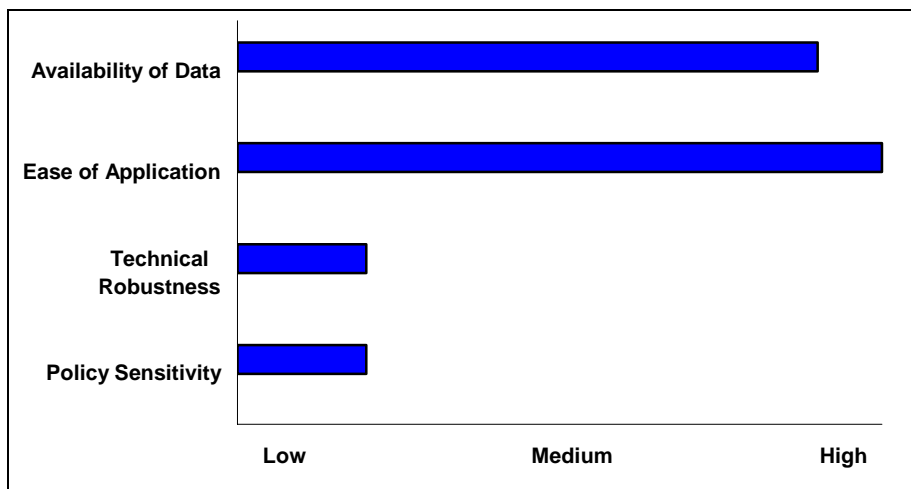
Colorado DOT, "Colorado State Implementation Plan for PM-10, Aspen Element." Revised September 22, 1994.

Colorado DOT, "Air Quality Analysis, A Technical Report to the State Highway 82 Entrance to Aspen Environmental Impact Statement," July 7, 1995.

Rogue Valley MPO, "2004-2007 Transportation Improvement Program and Air Quality Conformity Determination," August 26, 2003.

FORECASTING VMT WITHOUT A TDF MODEL

Method 2: Linear Projection of Total VMT, based on Regression Analysis, Apportioned by Functional Class



Description This methodology uses a simple linear regression in order to forecast future total VMT for a jurisdiction, and then apportiones the VMT to functional classes in the same ratio as the most recent year of VMT data. It is a simple method to project VMT using manual calculation procedures.

Method Applicability This method is applicable to any area without a TDF model. It is most appropriate for an area that is expected to maintain a stable rate of growth in population, economic activity, and vehicle travel. It may be useful (at least initially) for a new nonattainment area that has limited experience with regional emissions analysis.

Data Sources and Procedures *VMT Projection*
VMT projections are developed on a county basis based on the historical trend line (an ordinary least squares linear regression extrapolation of the latest ten years of data). The statistical analysis uses total VMT in order to avoid issues associated with reclassification of VMT over time due to the expansion of urbanized boundaries and other functional class shifts. Projected VMT is then apportioned to the functional classes in the same ratio as the most recent year of VMT data.

- Advantages**
- Relative simplicity of the approach.
 - Resource requirements likely to be small.
 - Rationale and data sources are generally accepted.

- Limitations**
- Methodology does not reflect factors that will influence future VMT growth, such as population growth, economic growth, land use changes, and major new developments. However, such items could be included in the regression analysis as an improvement to the existing methodology. As described above, this method will not be very accurate for an area that is expecting a change in growth rate (either more rapid or slower) from the historical rate.
 - Methodology is not sensitive to expected changes in transportation investments or policies. Any additional traffic growth associated with new facilities will need to be

analyzed separately. Upgrades of facilities to higher classifications will not be reflected.

- If applied in a donut area, methodology may not be consistent with the VMT estimation and projection techniques used in the metropolitan portion of the nonattainment and maintenance area. As a result, coordination with the MPO to insure consistency would be needed.

Example The approach has been used by the North Carolina DOT for the donut areas in North
Location Carolina where a metropolitan area's travel demand model includes the metropolitan planning area only and not the balance of the nonattainment or maintenance area.

Web sites:

<http://www.ptcog.org/emissions.pdf>

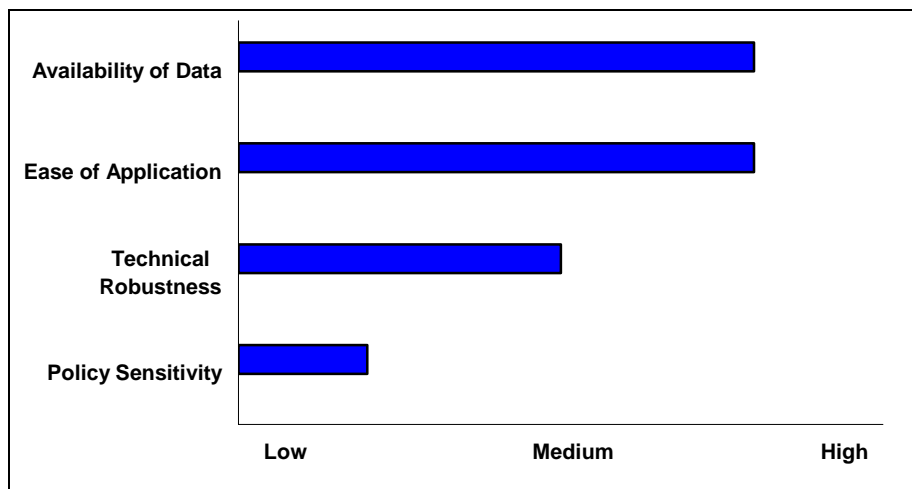
http://tocfs2.ci.high-point.nc.us/HPMPO/plans/LRTP04/Appendix_B_-_Conformity_Analysis_Report_Executive_Summary/High_Point_2030_LRTP_Conformity_Analysis_Report.pdf

References:

North Carolina DOT, Davidson County, and the North Carolina Department of Environment, "Emissions Analysis Report for the Transportation Plan for Rural Portion of Davidson County," September 27, 2002.

FORECASTING VMT WITHOUT A TDF MODEL

Method 3: Linear Projections of VMT by Functional Class, with Adjustments to Correct for Changes in Functional Class Categories



Description This methodology uses separate simple linear regressions in order to forecast future VMT for each roadway functional classification. In order to account for changes in road classifications over time, minor changes are “smoothed” by adjusting the VMT on a particular functional class for each year in proportion to any changes made in functional class mileage.

Method Applicability This method is applicable to any area without a TDF model. It is most appropriate for an area that is expected to maintain a stable rate of growth in population, economic activity, and vehicle travel. It may be useful (at least initially) for a new nonattainment area that has limited experience with regional emissions analysis.

Data Sources and Procedures *VMT Projection*
VMT forecasts are developed based on a linear regression for each functional class of roadway. However, in order to use historic data to conduct a linear regression by functional class, adjustments need to be made to correct for minor changes in functional class categories (associated with changes due to system upgrades).

Minor changes are “smoothed” by adjusting the historic annual VMT for a particular functional class in proportion to any subsequent changes made in functional class mileage (due to roadway upgrades). Per the equation below, this is done by multiplying VMT for each year by the ratio of mileage in the functional class in the current year to mileage in the VMT estimate year (for example, if current mileage on urban arterials is 105% of mileage in a historic year, due to system upgrades, VMT on urban arterials in the historic year will be multiplied by 1.05 in order to get an adjusted VMT estimate).

For each roadway functional class, for each historic year:

$$VMT_{adjusted-historic-year} = VMT_{historic-year} \times \frac{FunctionalClassMiles_{current-year}}{FunctionalClassMiles_{historic-year}}$$

This effectively adjusts the older VMT for a given functional class to account for roadways that have since been shifted into that functional class. Per the equation below, functional class VMT totals must then be adjusted to ensure that total VMT for each year does not change as a result of these adjustments. The VMT sum for each year is calculated, and the ratio of the original VMT sum to the new VMT sum is multiplied by the adjusted VMT value for each functional class.

For each roadway functional class, for each historic year:

$$VMT_{corrected-historic-year} = VMT_{adjusted-historic-year} \times \frac{VMT(All - Roadways)_{unadjusted-historic-year}}{VMT(All - Roadways)_{adjusted-historic-year}}$$

To avoid problems caused by larger discontinuities in historic trends by functional class (for example, due to changes in the definition of a functional classification at a particular time), linear regressions are conducted in a manner so they do not span such discontinuities. In other words, if a major jump takes place in 1990, the regression may disregard all data prior to 1990.

The procedures discussed above may be conducted at the statewide level in order to develop projected growth rates for each functional class that can then be applied at the local level.

Advantages

- Accounts for differences in growth rates on different types of roadways.
- Accounts for historical changes in road network, and can adjust for concerns about local links with sparse data.
- Rationale and data sources are generally accepted.

Limitations

- Methodology does not explicitly account for factors that will influence future VMT growth, such as population growth, economic growth, land use changes, and major new developments. As a result, it will not be very accurate for an area that is expecting a significant change in growth rate (either more rapid or slower) from the historical rate.
- Methodology is not sensitive to expected changes in transportation investments or policies. Any additional traffic growth associated with new facilities will need to be analyzed separately. Future upgrades of facilities to higher classifications will not be reflected.
- If a donut area, may not be consistent with the VMT estimation and projection techniques used in the metropolitan portion of the nonattainment or maintenance area. This work is done by the MPO and coordination on consistency would be important.

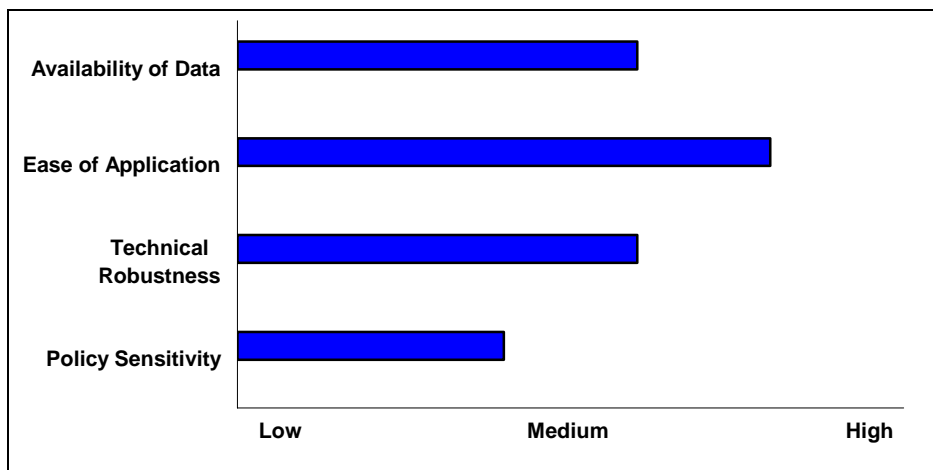
Example Location

Ohio Department of Transportation (DOT) uses TDF models for many small urban areas. Where there is no TDF model, Ohio DOT has used this procedure to forecast VMT. In this case, VMT estimates were only believed to be accurate at the statewide level, not the local level. As a result, the procedures for estimating future VMT growth rates were conducted at the statewide level for all functional classes in order to maintain consistency. The statewide growth rates were then applied to estimates of VMT by functional class for the area being analyzed.

Website: <http://www.dot.state.oh.us/urban/index.htm>
(See VMT forecasting procedures described under “documents” section:
<http://www.dot.state.oh.us/urban/data/vmt.doc>)

FORECASTING VMT WITHOUT A TDF MODEL

Method 4: Linear Projection of Interstate VMT and Population-based Forecast of Non-Interstate VMT



Description This methodology separates out non-Interstate and Interstate VMT, since non-Interstate VMT typically relates closely to population, while the Interstate traffic in rural and small urban areas involves predominantly through-traffic and is not closely correlated with local population growth. Interstate VMT is estimated based on historical trend line, while non-Interstate VMT is estimated based on a regression to predict non-Interstate VMT per capita, which is applied to projected population.

Method Applicability This method is applicable to small urban and rural areas, where Interstate highways make up a substantial proportion of VMT, and where population growth patterns may not reflect historical trends.

Data Sources and Procedures *VMT Projection* Interstate VMT is projected using linear regression based on historic traffic volumes.

Non-Interstate VMT is calculated by multiplying projected population by projected non-Interstate VMT per capita. Projected population can be taken from the MPO or state agency responsible for population projections. Non-Interstate VMT per capita is forecast based on a linear regression using historic estimates of VMT per capita for non-Interstate travel at the county level. This forecast recognizes that the amount of daily travel per person has increased historically and is likely to continue to increase. The resulting estimate of non-Interstate VMT is then apportioned to the functional classes in the same ratio as in the most recent year of data (also see Method #5 below for an alternative methodology for estimating non-interstate VMT).

- Advantages**
- Relatively simple approach yet accounts for most important roadway classification issues.
 - Use of per capita VMT provides better sensitivity to key factors that affect non-Interstate travel than methods that simply use historical VMT as the independent variable.
 - Resource requirements likely to be small.
 - Rationale and data sources are generally accepted.

- Limitations**
- Methodology does not fully reflect factors that will influence future non-Interstate VMT growth.
 - Methodology is not sensitive to factors affecting Interstate VMT growth rate.
 - Methodology is only somewhat sensitive to expected changes in transportation investments or policies.
 - For the local links without traffic counts, assumptions about traffic levels need to be made, and these assumptions should be documented and reasonableness reviewed each time a new conformity determination is made.

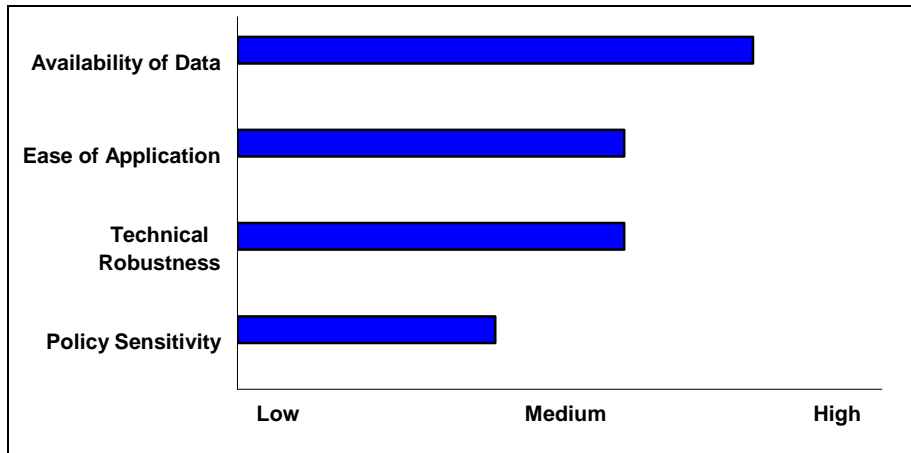
Example Location The approach has been used by the South Carolina Department of Transportation in Cherokee County.

References:

Gardner, John, "Vehicle Miles of Travel Projections and Speed Estimates for Rural Nonattainment and Maintenance Areas," South Carolina Department of Transportation.

FORECASTING VMT WITHOUT A TDF MODEL

Method 5: Corridor-based Analysis of Interstate VMT, Population-based Forecast for Non-Interstate VMT



Description This method is similar to methodology #4, but uses professional judgment and a corridor-by-corridor analysis of historic growth and anticipated growth in each corridor in order to estimate the growth rate for Interstate VMT rather than relying solely on linear projection of historic data. It also utilizes a slightly different approach for estimating non-Interstate VMT, relying heavily on statewide VMT data rather than county-level data.

Method Applicability This method is applicable to small urban and rural areas, where Interstate highways make up a substantial proportion of VMT, and where historical growth in Interstate VMT may overestimate future growth (this may be the case if historic growth has been especially rapid, and limited highway capacity constrains the level of future growth). It also is most applicable in locations where population growth patterns may not reflect historical trends.

Data Sources and Procedures *VMT Projection* Interstate VMT is projected using data on historic trends, but is assumed to decline somewhat based on limitation in highway capacity or other factors. A corridor-by-corridor analysis is conducted of historic VMT growth in order to develop an initial annual growth rate. An adjusted annual growth rate is then developed for purpose of projections based on professional understanding of the anticipated pace of traffic growth in each corridor.

An estimate of non-Interstate VMT is developed using an approach similar to the one described in methodology #4, which relies on projections of population and per capita VMT. However, in this case, statewide growth in non-Interstate VMT is estimated using statewide VMT data from HPMS and state population estimates. First, a linear regression is developed to predict statewide non-Interstate VMT as a function of population, based on historic data, as follows:

$$NonInterstateVMT = a \times Population + b$$

The base year non-Interstate VMT is then subtracted from the future year projection to calculate the projected growth in non-Interstate VMT. This statewide VMT growth is then allocated to the counties based on a combination of county population change and a projected increase in per capita VMT, as described below:

1. First, projected VMT per person is calculated for the analysis year by dividing the non-Interstate VMT calculated in the regression equation by the population projection in the analysis year.
2. The resulting estimate of VMT per capita is then multiplied by the base-year county population estimate in order to estimate future-year VMT associated with the existing population for the analysis year.
3. The county-level VMT estimates are then summed for the state to obtain the estimated statewide VMT associated with the existing population.
4. The difference between the resulting statewide VMT total (representing VMT associated with the base year population) and the forecasted total (from the regression analysis) is then calculated to obtain the estimated VMT due to population growth.
5. The VMT associated with population growth is then allocated to the county level based on each county's proportion of statewide population change between the base year and the forecast year. For example, if a county is responsible for 5% of the estimated population growth, then 5% of the VMT associated with population growth would be allocated to the county.

The resulting estimate of county-level non-Interstate VMT is then allocated to each functional class in the same proportion as in the HPMS baseline year.

- Advantages**
- Relatively simple approach yet accounts for most important roadway classification issues.
 - Use of per capita VMT provides better sensitivity to key factors that affect non-Interstate travel than methods that simply use historical VMT as the independent variable.
 - Use of statewide data helps to avoid potential inaccuracies associated with county-level VMT estimates.
 - Resource requirements are moderate.

- Limitations**
- Methodology does not fully reflect factors that will influence future non-Interstate VMT growth.
 - Use of estimated or assumed growth rates can introduce bias.
 - Methodology is only somewhat sensitive to expected changes in transportation investments or policies.

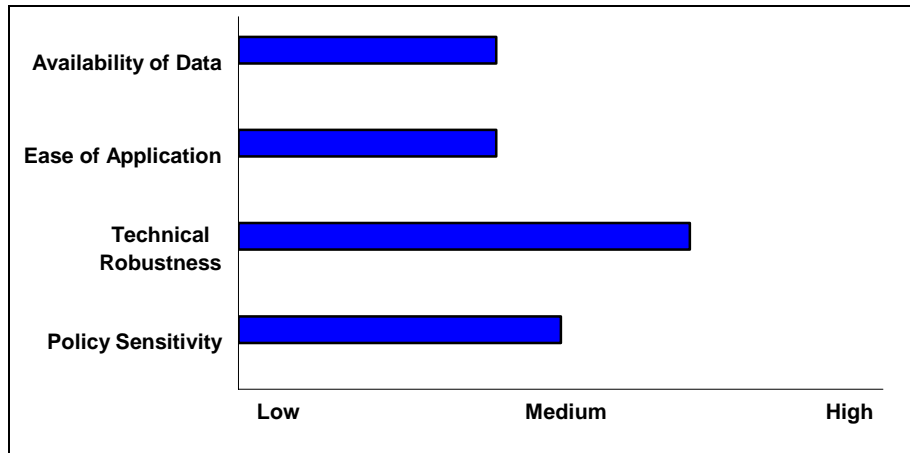
Example Location The approach has been used by the Kentucky Transportation Cabinet (KYTC) in locations where there is not a TDF model.

References:

M.L. Barrett, R.C. Graves, D.L. Allen, J.G. Pigman, G. Abu-Lebdeh, L. Aultman-Hall, S.T. Bowling, Analysis of Traffic Growth Rates, University of Kentucky Transportation Center, August 2001.

FORECASTING VMT WITHOUT A TDF MODEL

Method 6: Separate Forecasts by Functional Class based on VMT, Population, and Employment, with Growth Factor employing a Decay Function



Description This methodology involves developing separate forecasts of VMT by functional class. A unique aspect of this method is that it takes into account employment as a factor that influences VMT, and does not use a linear regression function. It employs a decay factor based on an assumption that future traffic growth will slow in the future compared to historic rates of growth. Estimates are adjusted to reflect current year HPMS VMT estimates.

Method Applicability This method is applicable to small urban and rural areas without a TDF model. It is particularly useful where there are significant differences between travel characteristics by road classification, and when there is empirical evidence of a declining trend in VMT growth.

Data Sources and Procedures *VMT Projection*
VMT forecasts for each county and functional class are based on traffic data and growth factors that reflect historic correlations between VMT and population and employment for each county and functional class. The growth factor employs a decay function assuming that VMT growth will taper off. Estimates are adjusted to reflect current year HPMS VMT estimates.

Advantages

- Methodology accounts for additional factors that influence VMT growth.
- Approach accounts for differences in VMT growth rates on different roadway functional classifications.

Limitations

- Use of estimated or assumed growth rates (decay function) can introduce bias.
- Resource and data requirements are the highest among the alternatives examined for areas without a TDF model.

Example The approach has been used by the Pennsylvania Department of Transportation for
Location all areas where there is not a TDF model.

Reference:

Michael Baker, Jr., Inc., "The 2002 Pennsylvania Statewide Inventory, Using MOBILE6, An Explanation of Methodology," November 2003.

2.5 METHODOLOGIES FOR FORECASTING VMT WITH A TDF MODEL

Areas that maintain a TDF model generally use the model outputs to estimate VMT. There are a variety of commercially available TDF model software packages in use, including TranPlan, TransCAD, TP+, Viper, MINUTP, EMME/2, and QRS2. Software is often supplemented by custom sub-routines not integrated into the package. The scope of these models also differs – some areas have urban area models, some county-level models, and a few have statewide models (which may not use commercial software) that provide county-level data. At least one State reported using both urban area models (for the MPO area) and a statewide model (for the donut areas outside of MPO and urban model boundaries).

TDF models offer greater sensitivity to changes in transportation investments or policies, compared to most manual calculation procedures. New facilities and improvements to existing facilities can be coded into the network. In estimating future VMT, the TDF model takes into account all of these improvements at once, predicting the most likely distribution of traffic on the future network. In contrast, most off-model calculation procedures cannot consider how all improvements together would affect traffic distribution across the network.

Adjustments to TDF model outputs are often required in order to make the results suitable for conformity analysis. Adjustments to the model outputs generally fall into three categories:

- 1) Adjustments to TDF model outputs to ensure that VMT results are appropriate for use in comparison with the emissions budget in a SIP (see section 2.5.1);
- 2) Methods to account for lower functional classification roadways (i.e., local roads) that are within the model area but not included within the model network (see section 2.5.2); and
- 3) Methods to estimate VMT for donut areas not covered by the TDF model (see section 2.5.3).

2.5.1 Adjustments to Model Output to Ensure Appropriateness for Emissions Analysis

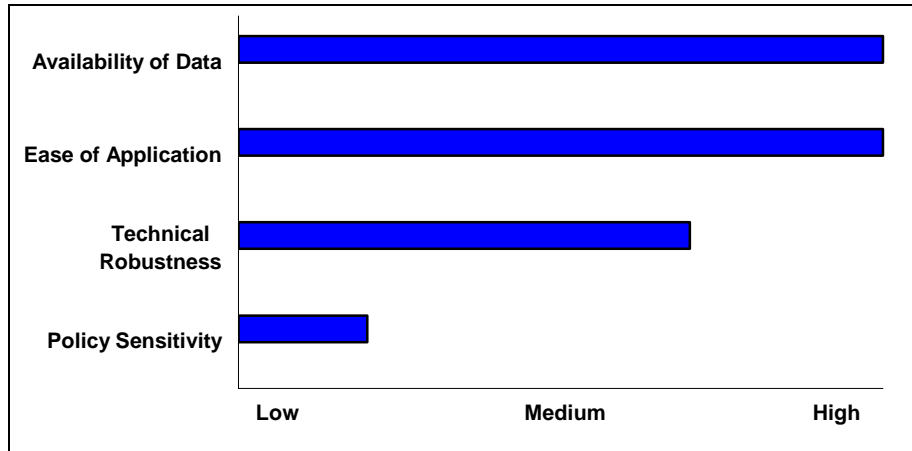
In cases where a TDF model is available, the model itself is generally used to estimate future VMT by functional class. However, some adjustments may be made to the estimates so they can be used for the regional emissions analysis. The adjustments are typically made either to improve the reliability of the estimates or to ensure that the resulting estimates are consistent with estimates from HPMS that were used in developing the emissions budget in the SIP.

Samples of adjustments include:

- Adjustment 1: Adjustment factor to scale modeled VMT estimate to HPMS VMT estimate (required under the transportation conformity rule)
- Adjustment 2: Adjustment to account for trip lengths that do not cover the entire link length in the model
- Adjustment 3: Detailed approach to incorporating external trips into a statewide TDF model (this approach essentially is a more detailed off-model procedure to come up with more accurate estimates of external trips)
- Adjustment 4: Use of seasonable adjustment factor

FORECASTING VMT WITH A TDF MODEL: ADJUSTMENTS TO MODEL OUTPUT

Adjustment 1: Adjustment Factor to Scale Modeled VMT Estimate to HPMS VMT Estimate



Description VMT estimates from the urbanized area TDF model are compared to the urbanized area VMT estimate from HPMS for each urban functional class. Adjustment factors are calculated for each roadway functional class to fit the modeled VMT estimates to the HPMS estimates. The adjustment factors are then applied to all forecast years to scale the forecasts.

Method Applicability This method is applicable to areas with a TDF model where the model does not include all roadway links, or does not represent an estimate of total regional VMT. This adjustment is required under the transportation conformity rule.

Data Sources and Procedures *VMT Estimation*
When a travel demand model is used to estimate VMT, those estimates must be checked against HPMS VMT estimates and adjusted if needed. The goal is to ensure, as best possible, that the travel demand model is forecasting VMT consistently with the VMT reported through the HPMS system.

VMT estimates from the TDF model are compared to the VMT estimate from HPMS for each functional class in the base year. Adjustment factors are calculated for each roadway functional class to fit the modeled VMT estimates to the HPMS estimates, as follows:

$$AdjustmentFactor = \frac{VMT_{HPMS}}{VMT_{TDF\ model}}$$

VMT Projection
VMT projections are made using the TDF model in a standard fashion. The adjustment factors for each functional class developed in the base year comparison are then applied to all forecast years to scale the forecasts.

- Advantages**
- Conceptually simple approach.
 - Data are readily available.
 - Required under the transportation conformity rule.
- Limitations**
- Relies on the accuracy of HPMS data.
 - Completely static with regard to effects of projects, other factors, etc. across functional classes for forecasts.

Example Location This adjustment is required under the transportation conformity rule, and always should be applied in areas with TDF models to come up with accurate forecasts. Michigan DOT, for instance, uses adjustment factors to scale the results of the urban area models that it maintains for all small urban areas. In Yuma County, Arizona, VMT figures on local roadways were scaled up since the model local roadway mileage was 136 miles, whereas the actual local roadway mileage was approximately 780 miles.

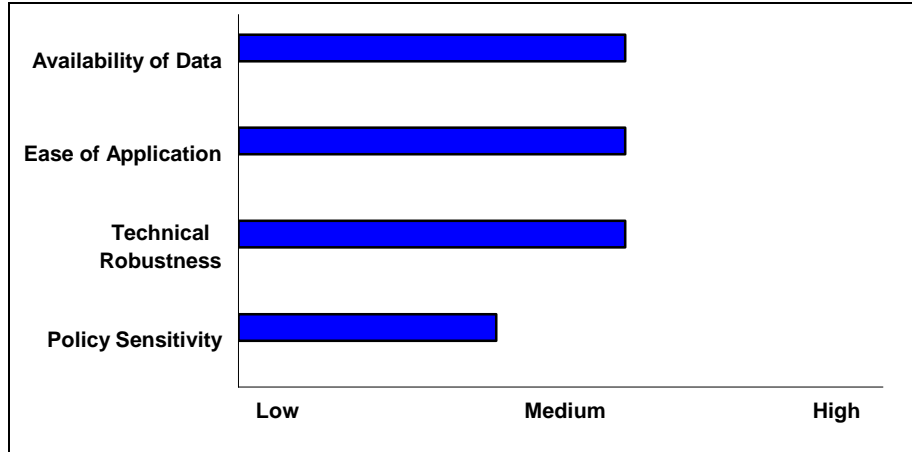
References:

Michigan DOT, Travel Demand Analysis Section. "Technical Documentation of the Procedures Used to Develop VMT and Speed Estimates for Michigan Non-Attainment Counties Containing a Modeled Urban Area." 1995.

Lima & Associates "Vehicle Particulate Emissions Analysis" prepared for ADOT, and Yuma MPO, May 2002.

FORECASTING VMT WITH A TDF MODEL: ADJUSTMENTS TO MODEL OUTPUT

Adjustment 2: Adjustment to Account for Trip Lengths that do not Cover the Entire Link Length



Description The standard calculation of link VMT (link volume x link length) assumes that vehicle trips travel the entire length of the link. This is not always the case, particularly for local roads in rural areas. As a result, an adjustment is made to scale VMT down for selected segments or classifications in order to better reflect actual travel activity.

Method Applicability This method is most applicable to areas in which the TDF model contains long road links and where substantial activity is likely to occur away from the endpoints of the links.

Data Sources and Procedures *VMT Estimation and Projection*
Baseline VMT is estimated for each link using a TDF model. Based on professional expertise, knowledge of a given location, or review of travel activity data, selected road links or classifications are subject to a downward adjustment to represent trips traveling a limited distance along the links. The adjustment factor is then applied to future forecasts on those links or functional classes.

Advantages

- Relatively simple approach.
- Better reflects regional VMT.

Limitations

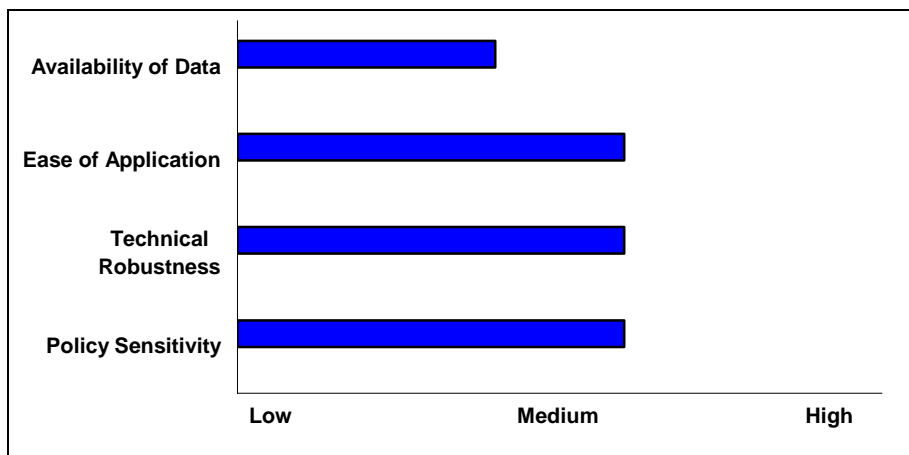
- Requires GIS capabilities and comprehensive road network data.
- Must be accounted for in TDF model calibration.

Example Location The approach has been used in Yuma County, Arizona, where final VMT was adjusted down in rural areas by a certain percentage for local paved roads and by another percentage for local unpaved roads.

Reference: Lima & Associates “Vehicle Particulate Emissions Analysis” prepared for ADOT, and Yuma MPO, May 2002.

FORECASTING VMT WITH A TDF MODEL: ADJUSTMENTS TO MODEL OUTPUT

Adjustment 3: Detailed Approach to Incorporating External Trips into TDF Model



Description TDF models account for internal trip generators and attractors (i.e., located within the model area) as part of trip generation, distribution, and mode split. They also account for external trips at the network assignment stage. This adjustment involves a detailed analysis of external trips associated with tourism in order to develop projections of VMT, which are added into the model’s VMT projections. Growth in external trips is estimated based on professional judgment using analysis of applicable variables.

Method Applicability This method is most applicable to areas where external trips make up a significant portion of total regional VMT, particularly small communities that are tourist destinations or have a great deal of freight activity utilizing a port or trucking facility. The level of detail in the approach can relate to the level of importance of the factor.

Data Sources and Procedures *VMT Estimation and Projection*
An off-model, customized procedure is developed to account for external trip purposes that may represent significant VMT and be sensitive to predictable factors. These may include external-internal trips and external-external (through) trips. Although these trips are typically accounted for in traffic assignment based on traffic counts, this procedure includes a detailed analysis and projection methodology to better predict potential changes in the rate of external trips. For tourist trips, projected population increases in states that supply the largest number of visitors and anticipated growth in service employment can be used to estimate the number of external trips and VMT generated.

Advantages

- Required to account for all components of regional VMT.
- Addresses an important factor for certain rural and small urban areas.
- Flexibility in degree of precision vs. level of effort.
- Sensitive to factors that influence external trips, which may be different from internal trips.

- Limitations**
- Custom off-model procedures may require additional resources and technical expertise.
 - External trip adjustments often rely on professional judgment and thereby open to potential bias or error.
 - May be data intensive if external trip estimates are based on vehicle surveys or economic data.

Example Location The approach has been used by the Maine DOT in its statewide TDF model. The statewide model relies on population demographics, employment, and economic activity in order to forecast VMT. A REMI model¹⁰ was used to establish base year and forecast year population and employment for nine regions in Maine. By using a REMI model for population and employment estimates Maine's statewide TDF model accounted for vehicle travel that may be specifically associated with large transportation investments.

A separate category of external trips was developed for tourist travel into Maine. Maine DOT reviewed population increases in states that supply the largest number of visitors to Maine (Massachusetts, Connecticut, Rhode Island, New York, and New Jersey) and projected growth in service employment in order to come up with an estimated increase in external trips.

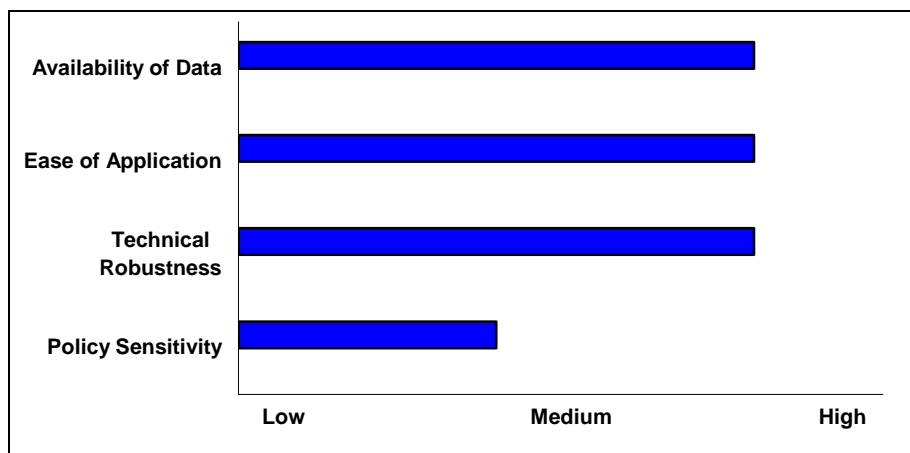
Website: <http://www.maine.gov/mdot/air-quality-noise/air-quaility-noise.php>

Reference: Maine Department of Transportation (Bureau of Planning), "The 2002 - 2004 STIP Conformity Analysis for Maine's Nonattainment and Maintenance Areas," August 2001.

¹⁰ A REMI model (Regional Economic Models, Inc.) is a commonly used economic-forecasting and policy-analysis model;

FORECASTING VMT WITH A TDF MODEL: ADJUSTMENTS TO MODEL OUTPUT

Adjustment 4: Use of Seasonal Adjustment Factor



Description An adjustment is made to scale average annual daily VMT to reflect a seasonal estimate of average daily VMT, either summer or winter, depending on the pollutant of concern. The seasonal adjustment is made to ensure that the resulting VMT estimate is consistent with assumptions used in the SIP emissions budget. The methodology can be used with or without a TDF model.

Method Applicability This method is most applicable to areas where there are significant seasonal variations in travel activity (e.g., due to tourism) or where the SIP budget was developed with a seasonal adjustment.

Data Sources and Procedures *VMT Estimation and Projection*
A scaling factor is developed to scale the annual average daily VMT estimates to reflect a summer or winter season. The scaling factor is developed by dividing average daily traffic in the season of interest by average annual daily traffic (AADT). The data come from traffic surveys conducted at various points in the year.

Advantages

- Better reflects actual travel activity for period of concern.
- Simple methodology with limited resource requirements.

Limitations

- Requires enough data on travel at different times of the year for all road types in order to ensure accuracy.

Example Location Pennsylvania DOT (Penn DOT) developed an automated software package called PPSUITE, which takes the daily volumes from its Roadway Management System (RMS) that represent AADT, and seasonally adjusts the volumes to reflect an average weekday in July. The Pennsylvania DOT developed the adjustment factors for each functional class of roadway based on the ratio of weekday July traffic counts to the RMS's data on annual average volumes.

Reference:

Michael Baker, Jr., Inc., "The 2002 Pennsylvania Statewide Inventory, Using MOBILE6, An Explanation of Methodology," November 2003.

2.5.2 Methods to Estimate VMT for Local Roads not Covered by TDF Model

Many TDF models only include the higher functional classifications of roadways, not roadway functional classes with low traffic volumes such as local roads. Accounting for future local road links in TDF models is often problematic since the construction of local streets is dependent upon private residential development and is not included in regional transportation plans, and therefore, it is difficult to determine where and how many local roads will be built in future years. Moreover, some areas may not have an accurate inventory of all local roads. However, in order to estimate regional emissions, estimates of VMT on the entire road network are required.

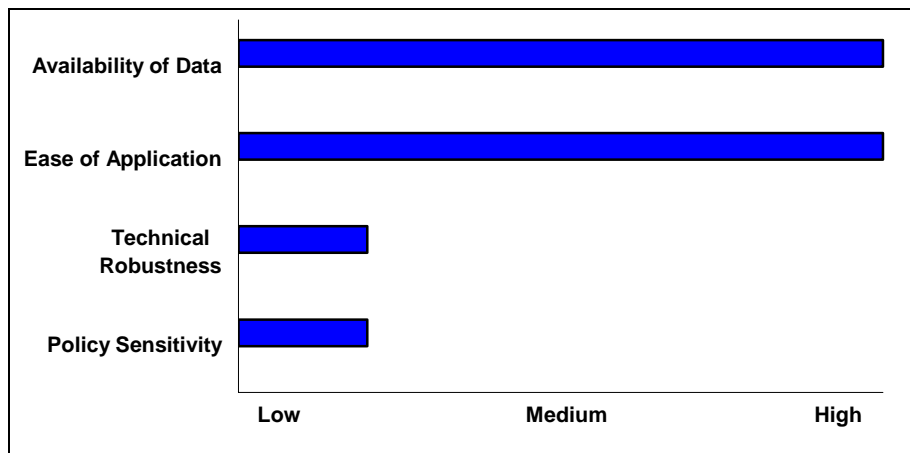
As a result, areas with TDF models typically use off-model procedures to forecast VMT on local roadways. Several methods can be used to estimate VMT for local roads that are not covered by a regional TDF. Some of the methods described earlier in Section 2.3 (i.e., Method 1: Use statewide HPMS data to calculate the proportion of local road VMT to collector VMT; or Method 2: Use county-level HPMS estimates to develop a statistical relationship between local road VMT and collector VMT) can also be applied in areas with TDF models.

The methods described in this section rely on information from the TDF model. The two sample methods are:

- Method 1: Assume percent of modeled VMT
- Method 2: Use HPMS estimate of local road VMT and apply VMT growth rate on analogous function class(es) from the model
- Method 3: Off-model GIS analysis using traffic analysis zone (TAZ)-level trip data and number of dwelling units

FORECASTING VMT WITH A TDF MODEL: ESTIMATING VMT FOR LOCAL ROADS

Method 1: Assume Percent of Modeled VMT



Description Many TDF models do not produce VMT estimates for roadway functional classes with low traffic volumes such as local roads. Under this method, local road VMT is assumed to be a percentage of modeled VMT.

Method Applicability This method is applicable to all areas where a roadway classification (i.e., local roads) in the modeled area is not represented in the model. It is most applicable to an area where the road network is expected to remain relatively unchanged (i.e., the area is not planning to add a new major freeway or arterial facility).

Data Sources and Procedures *VMT Estimation and Projection*
VMT on local roads is assumed to be a consistent percentage of modeled VMT. For example, if local road VMT is assumed to be 10% of the modeled VMT, and the model produces an estimate of 100,000 daily vehicle miles, then local road VMT would be estimated as 10,000 vehicle miles, for a regional total of 110,000 vehicle miles. The percentage may be determined based on available data sources, such as HPMS figures for the county or state by functional class.

Advantages

- Very simple approach and straightforward to explain.
- Data are readily available.
- Resource requirements are small

Limitations

- Using a constant share of local road VMT to non-local road VMT may not be appropriate for projections if a major new highway facility is planned that could change the balance between local road traffic and total traffic. A constant percentage also would not be accurate if different growth rates are expected for interstate (through) traffic associated with external trips and traffic associated with local population.
- Percentage selected may be highly uncertain. If based on statewide HPMS data, the county under consideration may not reflect state patterns. If based on county-level HPMS data, there are major uncertainties in these estimates.

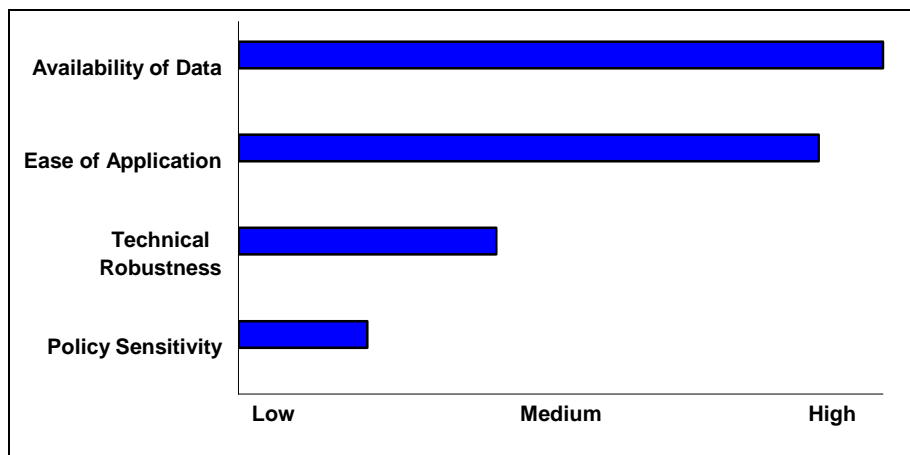
Example This methodology was used Medford-Ashland (Klamath County), Oregon, by the
Location Rogue Valley MPO in its air quality conformity determination for the 2004-2007
TIP. The Rogue Valley MPO has a TDF model that estimates average daily VMT
within the MPO area but does not include local streets. In this case, VMT on local
streets in the MPO area was assumed to be 10 percent of the modeled VMT.

References:

Rogue Valley MPO, "2004-2007 Transportation Improvement Program and
Air Quality Conformity Determination," August 26, 2003.

FORECASTING VMT WITH A TDF MODEL: ESTIMATING VMT FOR LOCAL ROADS

Method 2: Use HPMS Estimate and VMT Growth Rate on Analogous Functional Classes from Model



Description This methodology is similar to Method #1, but relates local road VMT to analogous functional classes. HPMS data are used to estimate VMT on these lower volume functional classes for the base year. Growth in VMT for functional roadway classes not included in the TDF model is assumed to be parallel to VMT growth of functional classes that are represented in the model (e.g., local roads are assumed to have the same growth rate as collectors).

Method Applicability This method is applicable to all areas where a roadway classification (i.e., local roads) in the modeled area is not represented in the model. It is easiest to apply when this discrepancy is congruous with functional classes.

Data Sources and Procedures *VMT Estimation*
VMT estimates are taken directly from the TDF model for functional roadway classes included in the model. For those classes of roads not included in the model, the VMT estimate is taken directly from HPMS.

VMT Projection
VMT growth rates for non-represented functional classes are assumed to be parallel to those of a functional class that is represented in the model (e.g., local roads are assumed to have the same growth rate as collectors). For example, if the model forecasts that VMT on rural collectors will increase 15% between the base year and the forecast year, then VMT on rural local roads would be assumed to increase by 15%.

Advantages

- Simple and straightforward approach
- Data are readily available.

Limitations

- HPMS VMT estimates for local roads generally depend on a small sample of roads within a given county and may therefore be unreliable.
- VMT on functional classes not included in the model (i.e., local roads) may not experience the same growth rate as classes included in the model.

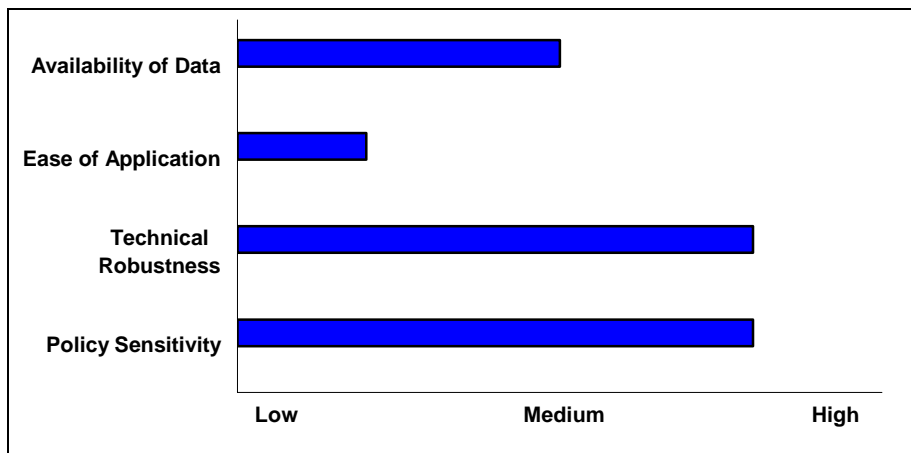
Example Location The approach has been used by Michigan DOT in the portion of Allegan County that is outside of the area covered by the model used for the MPO area by the Macatawa Area Coordinating Council (MACC).

References:

“Technical Documentation of the Procedures Used to Develop VMT and Speed Estimates for Michigan Non-Attainment Counties Containing a Modeled Urban Area,” Travel Demand Analysis Section, Michigan DOT, 1995.

FORECASTING VMT WITH A TDF MODEL: ESTIMATING VMT FOR LOCAL ROADS

Method 3: Off-Model GIS Analysis Using TAZ-Level Trip Data and Number of Dwelling Units



Description For low traffic volume road links not represented in the model network (usually local roads), VMT estimates are developed using a GIS application. Baseline VMT is estimated for each local roadway link in a traffic analysis zone (TAZ) based on the link’s length and the number of vehicle trip-ends generated within the TAZ. Future year VMT is estimated based on projected increases in the number of dwelling units within the TAZ and an estimate of future VMT per dwelling unit developed based on regression analysis of historical data.

Method Applicability This method is applicable to all areas where not all road links in the modeled area are represented in the model.

Data Sources and Procedures *VMT Estimation*
Baseline VMT is estimated for each local link in a traffic analysis zone (TAZ), based on the link length (derived using a GIS application) and the number of vehicle trip-ends generated within the TAZ. These two factors may be statistically evaluated against those local roads for which data are available, and a relationship thus developed.

VMT Projection
Future year VMT on local roads is estimated as base year VMT plus additional VMT associated with new development. Since the number of lane miles of new local roads is unknown, the incremental VMT is estimated based on the projected increase in the number of dwelling units in the TAZ and an estimate of daily VMT on local roads per dwelling unit. Local road VMT per dwelling unit is estimated based on a linear regression of historical values from travel surveys.

- Advantages**
- Relatively robust and technically appropriate.
 - Sensitive to changes in population and development patterns.

- Limitations**
- Requires GIS capabilities and comprehensive road network data.
 - Requires additional data (such as number of dwelling units and VMT per dwelling unit).
 - Method for estimation requires cross-checks to insure VMT is consistent with empirical data.

Example Location The approach has been used in Yuma County, Arizona, where local roads in the regional transportation network were not represented in the TransCAD model.

An inventory was performed on all local streets in the region to obtain relevant information, such as their location and surface type. In this case, link VMT for local roads in the base year was calculated using the equation:

$$LinkVMT = \frac{TripEnds\ in\ TAZ}{Sum\ of\ length\ of\ links\ in\ TAZ\ in\ miles} \times (Length\ of\ link\ in\ miles)^2$$

The VMT for future off-network links could not be estimated by the foregoing expression, since it is difficult to estimate the future construction of local roads. However, a simple linear regression analysis revealed that a relationship exists between the VMT and the number of dwelling units in a TAZ.

The analysis found that, on average, daily VMT on local roads for a TAZ increased by 1.22 mile for every increase in one dwelling unit. The increase in VMT on local roads for a specific TAZ was thus estimated as 1.22 times the number of dwelling units added to the TAZ between the base year and the future year.

References:

Lima & Associates “Vehicle Particulate Emissions Analysis” prepared for ADOT, and Yuma MPO, May 2002.

2.5.3 Methods to Estimate VMT in Donut Areas not Covered by TDF Model

In many cases, the geographic area covered by an MPO TDF model is inconsistent with the boundaries of the non-attainment or maintenance area that must be examined for the regional emissions analysis. In cases where the non-attainment or maintenance area is larger than the MPO planning area covered by the TDF model, the total VMT for the entire area is usually estimated through a two part process: 1) the MPO's TDF model is used to estimate VMT in the MPO area (along with any necessary adjustments, as discussed in sections 2.5.1 and 2.5.2), and 2) separate off-model approaches are used to estimate VMT in the portion of the nonattainment or maintenance area outside of the coverage of the TDF model (i.e., the donut area).

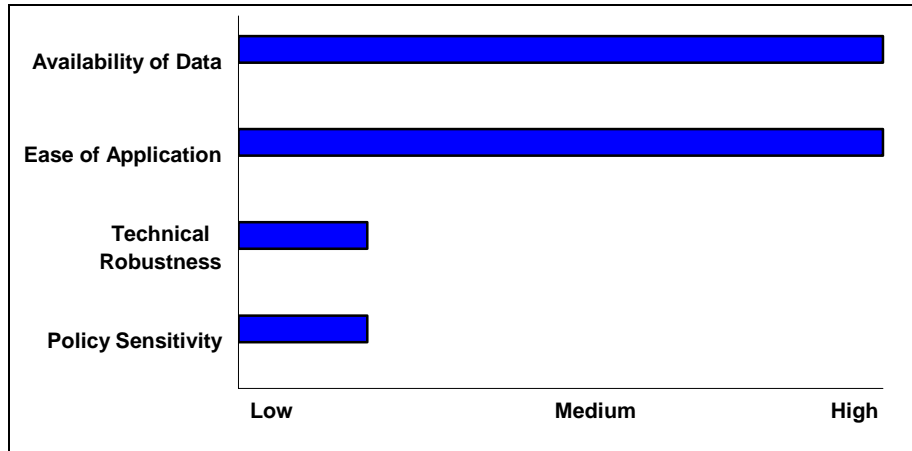
A range of off-model approaches can be used to estimate VMT for the donut area. This section identifies three methods that utilize outputs of the TDF model:

- Method 1: Develop projection of countywide VMT and subtract modeled VMT estimate
- Method 2: Use traffic counts and other projections for higher-classification roadways, and apply ratio from model to estimate VMT on lower-classification roadways
- Method 3: Use a statewide model and subtract estimates from urban area model

In addition, the methods discussed in section 2.4 for forecasting VMT without a TDF model typically can be applied in donut areas.

FORECASTING VMT WITH A TDF MODEL: ESTIMATING VMT FOR DONUT AREAS

Method 1: Subtract Modeled VMT from Projection of Countywide VMT



Description Forecast county-level VMT is determined by linear projections of HPMS or supplemental data for each functional class. The TDF model provides forecasts for the modeled area. The modeled area VMT is then subtracted from the countywide VMT forecast to obtain an estimate of the donut area VMT by functional class.

Method Applicability This method is applicable for any nonattainment or maintenance area where only a portion of the area is covered by a TDF model. It is most appropriate for an area that is expected to maintain a stable rate of growth in population, economic activity, and vehicle travel.

Data Sources and Procedures *VMT Estimation*
Countywide VMT estimates are based on estimates of Annual Average Daily Traffic (AADT), drawn from the best available data sources. For many areas, the annual HPMS VMT estimates reported to FHWA are the best available data. Some states also collect additional traffic counts and may have better estimates of traffic at the county or MPO level. For local road links without counts, assumptions of AADT can be made. VMT values for the modeled area are subtracted from the county-wide values by functional class to get the base year VMT by functional class for the donut area.

VMT Projection
VMT projections are developed on a county basis based on the historical trend line (e.g., an ordinary least squares linear regression extrapolation of the latest ten years of data). The statistical analysis can use total VMT in order to avoid issues associated with reclassification of VMT by functional class over time due to the expansion of urbanized boundaries and other functional class shifts. Projected VMT is then apportioned to the functional classes in the same ratio as the most recent year of VMT data.

The modeled area VMT forecast is then subtracted from the countywide VMT forecast for each functional class to obtain estimates of the donut area VMT by functional class.

- Advantages**
- Relative simplicity of the approach.
 - Resource requirements likely to be small.
 - Rationale and data sources are generally accepted.
- Limitations**
- For the non-modeled area, this methodology does not reflect factors that will influence future VMT growth, such as population growth, economic growth, land use changes, and major new developments. As a result, it will not be very accurate for an area that is expecting a change in growth rate (either more rapid or slower) from the historical rate or a growth rate very different from the modeled area.
 - For the non-modeled area, the methodology is not sensitive to changes in transportation investments or policies. Any additional traffic growth associated with upgrades of existing facilities or new facilities needs to be analyzed separately.
 - The countywide projections may not be consistent with the VMT projections developed for the modeled portion of the nonattainment or maintenance area.
 - Any uncertainty regarding the countywide data (e.g., data limitations in HPMS) will be reflected and possibly magnified in the non-modeled area, as the subtraction of the modeled area VMT means all the county's data variance will be attributed to a sub-area of the county. Moreover, the methodology does not directly relate the rate of growth in the modeled area with the donut area, although they presumably should be somewhat related due to their proximity.

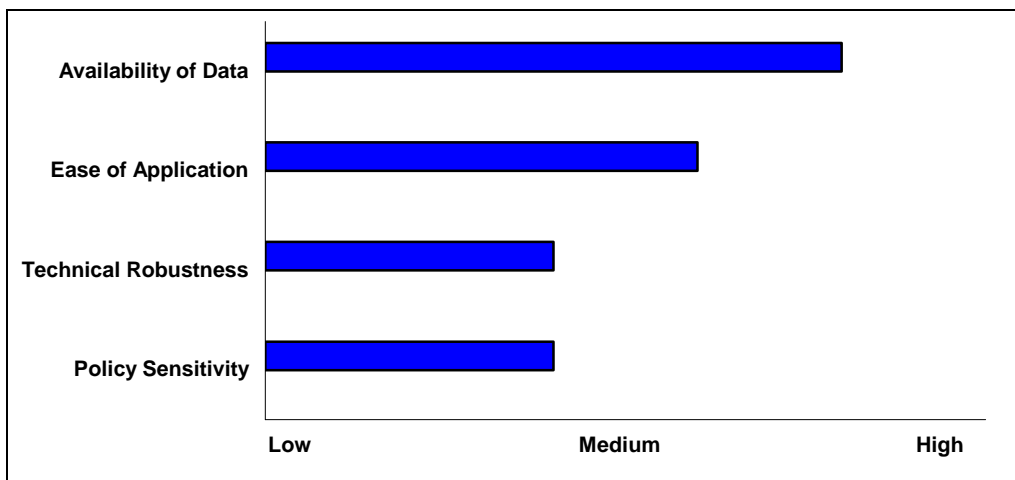
Example Location The approach has been used for the donut area of Sheboygan County, Wisconsin, where The Bay-Lake Regional Planning Commission conducts the conformity analysis for the Sheboygan County maintenance area using a regional travel demand model for the area within the MPO boundary, and simpler HPMS-based forecasting methodology for the rural donut portion of the county.

References:

Bay-Lake Regional Planning Commission, Wisconsin DOT, and Wisconsin Department of Natural Resources, *Assessment of Conformity of the Year 2025 Sheboygan Area Transportation and the 2004-2007 Sheboygan Metropolitan Planning Area Transportation Improvement Program (TIP) with Respect to the State of Wisconsin Air Quality Implementation Plan*, Fall 2003.

FORECASTING VMT WITH A TDF MODEL: ESTIMATING VMT FOR DONUT AREAS

Method 2: Develop Independent Projections for High-ADT Roadways, and Proportions from Model Area for Other Functional Classes



Description This method involves a combination of other methodologies. For high-ADT roads (freeways and major arterials), VMT are estimated from traffic data and estimated traffic growth rates are applied. For low-ADT roads (minor arterials, collectors, and local roads), the ratio of VMT on high- to low-ADT roads from the modeled area is assumed to apply for the non-modeled area.

Method Applicability This method is applicable for the non-modeled portion of a nonattainment or maintenance area or for any county in a nonattainment or maintenance area where only a portion of the area is covered by a TDF model.

Data Sources and Procedures *VMT Estimation and Projection*
An estimate of baseline VMT on high-ADT roads is developed by multiplying ADT on these road links by the link length. The ADT figures come from traffic counts collected along freeways and major arterials. To forecast future VMT, an estimated annual traffic growth rate is applied to the baseline estimate. The traffic growth rate is estimated based on historical data and/or information on factors that may affect future traffic growth.

VMT on low-ADT roads is then estimated using the ratio of VMT on low- to high-ADT roads from the modeled area, as follows:

$$LowADT\ Road\ VMT_{donut\ area} = HighADT\ Road\ VMT_{donut\ area} \times \frac{LowADT\ Road\ VMT_{model}}{HighADT\ Road\ VMT_{model}}$$

For example, if low-ADT roads contribute 30% of the VMT of high-ADT roads in the modeled area, VMT on low-ADT roads in the donut area is assumed to be 0.3 times VMT on high-ADT roads in the donut area.

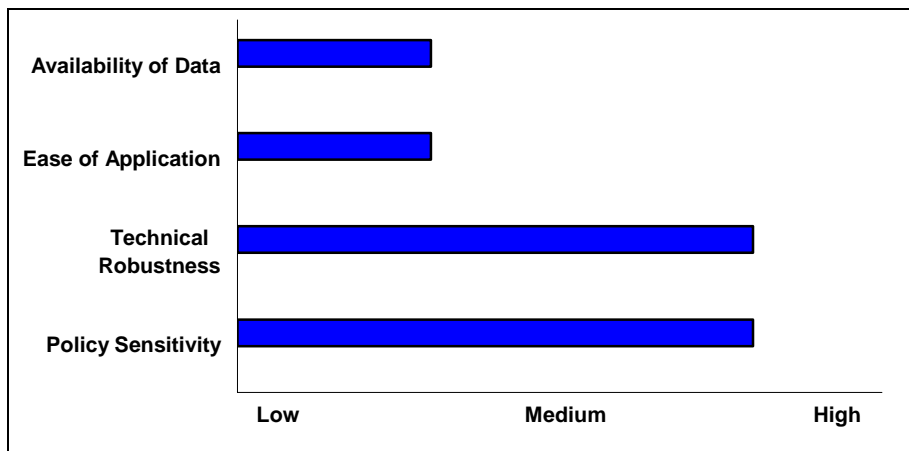
- Advantages**
- Flexibility of the approach.
 - Resource requirements likely to be small – uses existing data.
 - Rationale and data sources are generally accepted.
- Limitations**
- Ratio of low- to high-ADT road VMT in the modeled area may not reflect ratio in the nonmodeled area if the characteristics of the roadway network differ significantly (for example, if the nonmodeled area contains very few homes and a higher proportion of through traffic than the modeled area).
 - High degree of discretion makes method more open to introduction of bias and opinion.
- Example Location**
- The approach has been used in Medford-Ashland (Klamath County), Oregon, by the Rogue Valley MPO area for the conformity analysis of the 2004-2007 TIP. The Rogue Valley MPO has a TDF model that estimates average daily VMT within the MPO. An “off-model” calculation was conducted for roadways outside the MPO area. VMT on arterials and interstates in non-MPO areas was estimated based on traffic counts and estimated traffic growth rates developed by the Oregon Department of Transportation; VMT on collectors and local roads in non-MPO areas was estimated based on the same ratio of VMT on these roads to arterials and interstates as inside the MPO area.

References:

Rogue Valley MPO, “2004-2007 Transportation Improvement Program and Air Quality Conformity Determination,” August 26, 2003.

FORECASTING VMT WITH A TDF MODEL: ESTIMATING VMT FOR DONUT AREAS

Method 3: Use of Statewide Model for Non-MPO TDF Model Area



Description An MPO’s TDF model is used for the MPO planning area and a statewide TDF model is used for portions of the nonattainment or maintenance area outside of the MPO boundary. Both models rely largely on HPMS VMT data. For the donut area, the estimate of VMT from the MPO model is subtracted from the total countywide VMT estimate from the statewide model to determine VMT in the donut area.

Method Applicability This method is applicable for a nonattainment or maintenance area where only a portion of the area is covered by an MPO TDF model and where a statewide model is available.

Data Sources and Procedures *VMT Estimation and Projection*
Base year and future year estimates of VMT for the MPO planning area are calculated using the MPO’s TDF model. Base year and future year estimates of countywide VMT are developed using the statewide TDF model (Since statewide models do not include all roadway links, expansion factors are developed for each functional class by taking the HPMS county-level VMT estimate and dividing by the modeled VMT estimate for each functional class; the expansion factors by functional class are then applied to all future year VMT forecasts).

Estimates of VMT from the MPO’s TDF model are then subtracted from the total countywide VMT estimates from the statewide TDF model to determine VMT in the portion of the county not covered by the MPO’s TDF model.

Local roads are not incorporated into statewide models, so county-level HPMS figures are used for the base year. VMT growth for those local roads is assumed to parallel growth on collectors, and future year VMT figures are calculated accordingly.

- Advantages**
- Rationale and data sources are well accepted.
 - Use of statewide TDF model provides greater robustness and more sensitivity to changes in the highway network than off-model methods.

- Limitations**
- The need for a separate statewide model limits the applicability of this method; implementing one solely for this purpose is unlikely to be an efficient use of resources.
 - For the donut area (and potentially the MPO area), local road links not represented in the models need to be estimated based on HPMS-estimates that are less robust.

Example Location The approach has been used by Michigan DOT for donut areas outside of MPO boundaries in small urban areas, such as Allegan County. Michigan DOT maintains a statewide TDF model, which is used in these analyses.

References:

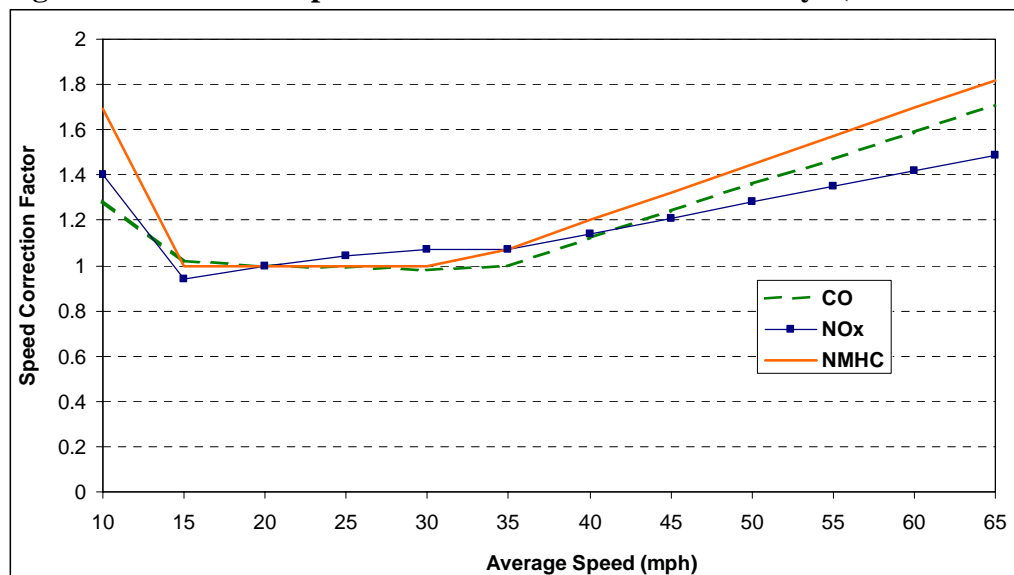
Michigan DOT, Travel Demand Analysis Section. "Technical Documentation of the Procedures Used to Develop VMT and Speed Estimates for Michigan Non-Attainment Counties Containing a Modeled Urban Area." 1995.

3 SPEED ESTIMATION AND FORECASTING EXAMPLES

3.1 BACKGROUND – IMPORTANCE OF SPEED ESTIMATES

Emission rates can vary widely with vehicle speed. Figure 1 shows the “speed correction factors” used in MOBILE6 for freeways for Tier 1 vehicles, which are used to scale emission rates from their base value (at 19.6 mph) to a value appropriate for a given speed. Per mile emission rates for particulate matter from exhaust and break and tire wear do not vary with speed in MOBILE6.

Figure 1: MOBILE6 Speed Correction Factors for Freeways (Tier 1 vehicles)



Source: *Facility Specific Speed Correction Factors*, Draft, U.S. EPA, Report Number M6.SPD.002, August 1999.

To account for the effects of speed, MOBILE6 calculates emission rates that are specific to each speed grouping (called “speed bin”). The speed bins are defined in 5 mph increments. When developing area-wide emissions estimates, users typically input the share of VMT that occurs at the different speed levels, and MOBILE6 then weights the speed-specific emission rates by VMT to produce a composite emission factor.

3.2 MOBILE6 REQUIREMENTS FOR SPEED

MOBILE6 accounts for speed effects by calculating emission rates specific to each speed, then weighting the speed-specific emission rates by VMT to produce a composite emission factor (by facility type). Thus, when developing area-wide emissions estimates, users have the option of inputting the fraction of VMT that occurs at the different speed levels, or rely on the model default values for the distribution of VMT by speed. The necessary level of detail of speed information supplied by the model user depends on local conditions and the intended uses of the emissions estimates (e.g., area-wide inventory vs. photochemical modeling).

VMT Distribution by Speed and by Hour (most detailed)

The greatest level of detail a user can provide for speed information is to specify the distribution of VMT by speed and by hour of day. This is accomplished using the SPEED VMT command in MOBILE6. For each hour of the day, the user provides the fraction of VMT that occurs in each of 14 speed “bins,” shown in Table 1.

Table 1: MOBILE6 Speed Bins

Number	Abbreviation	Description
1	2.5 mph	Average speeds 0-2.5 mph
2	5 mph	Average speeds 2.5-7.5 mph
3	10 mph	Average speeds 7.5-12.5 mph
4	15 mph	Average speeds 12.5-17.5 mph
5	20 mph	Average speeds 17.5-22.5 mph
6	25 mph	Average speeds 22.5-27.5 mph
7	30 mph	Average speeds 27.5-32.5 mph
8	35 mph	Average speeds 32.5-37.5 mph
9	40 mph	Average speeds 37.5-42.5 mph
10	45 mph	Average speeds 42.5-47.5 mph
11	50 mph	Average speeds 47.5-52.5 mph
12	55 mph	Average speeds 52.5-57.5 mph
13	60 mph	Average speeds 57.5-62.5 mph
14	65 mph	Average speeds >62.5 mph

The distribution of VMT by speed will vary by roadway functional class. The four functional classes in MOBILE6 are as follows:

- Freeway (excluding ramps)
- Arterial/collector
- Local roadway
- Freeway Ramp

MOBILE6 allows users to enter a distribution of VMT by speed only for freeways and arterials/collectors. For local roadways and freeway ramps, the average speed in the model is fixed at 12.9 mph and 34.6 mph, respectively, and cannot be modified. Thus, a MOBILE6 user that provides the most detailed local speed information possible will input a 24 x 14 x 2 matrix of VMT fractions (24 hours in the day, 14 speed bins, 2 facility types). EPA recommends that local estimates at this level of detail be developed for non-attainment areas that are classified as moderate or above and that are required to perform photochemical modeling. Most small urban and rural areas are not expected to provide this level of detail, and most are unlikely to have the data necessary to develop such inputs.

VMT Distribution by Speed

A simpler option is to provide localized data for VMT fractions by speed bin for an entire 24-hour period (i.e., no local information on variation by hour of day). For the development of an on-road emission inventory or forecast for SIP or conformity purposes, EPA expects nonattainment areas that are classified as moderate or above to use their own such specific estimates of VMT by average speed.¹¹

This option might be used, for example, by a region that runs a travel demand forecasting (TDF) model for a 24-hour period, but has little data on how the VMT distribution by speed varies by hour of the day. The TDF model will provide the VMT and speed on every modeled link. Using the modeled speed (or some other derivation of speed), the VMT on each link is assigned to one of the 14 speed bins (separately for freeways and for arterials/collectors). The VMT in each speed bin is then divided by the sum of all the VMT to calculate the VMT fractions.

As an illustration, Table 2 shows the VMT and VMT fractions by speed bin for freeways and arterials used for a 1995 inventory for Ada County, Idaho. In this example, most freeway VMT occurs in the 47.5 mph to 62.5 mph range and most arterial VMT occurs in the 27.5 mph to 37.5 mph range.

Table 2: Example of Distribution of VMT by Speed for Ada County, 1995

Speed Bin (mph)	VMT		VMT Fraction	
	Freeway	Arterial	Freeway	Arterial
0.0 -2.5	0	0	0	0
2.5 -7.5	0	0	0	0
7.5 - 12.5	0	0	0	0
12.5 - 17.5	147	5	0.0018	0.0000
17.5 - 22.5	230	1,669	0.0027	0.0098
22.5 - 27.5	2,318	7,720	0.0277	0.0454
27.5 - 32.5	468	56,278	0.0056	0.3309
32.5 - 37.5	0	67,940	0	0.3995
37.5 - 42.5	0	15,866	0	0.0933
42.5 - 47.5	7,407	20,578	0.0885	0.1210
47.5 - 52.5	42,903	0	0.5128	0
52.5 - 57.5	14,612	0	0.1747	0
57.5 - 62.5	15,574	0	0.1862	0
62.5 - 67.5	0	0	0	0
Total	83,659	170,056	1.0	1.0

Source: *Guidance for the Development of Facility Type VMT and Speed Distributions*, U.S. EPA, Report Number M6.SPD.004, February 1999.

¹¹ *Technical Guidance on the Use of MOBILE6.2 for Emission Inventory Preparation*, U.S. EPA, August 2004.

MOBILE6 still requires users to input a VMT distribution by speed for each hour of the day in order to use the SPEED VMT command. If the region does not have hourly-specific speed data (i.e., speeds reflect a daily average or peak and off-peak), then the same values may be used for multiple hours in order to make a complete set of hourly values for the MOBILE6 input file.¹² Alternatively, a user could run MOBILE separately for each speed bin and facility type using average speeds (as described below), then calculate a composite emission factor outside the model (e.g., in a spreadsheet).

Average Speed

If a region has no acceptable information regarding the distribution of VMT by speed, but does have some local information regarding the average speed by facility type, then MOBILE6 allows users to enter a single average speed for the freeway and arterial/collector functional classes using the AVERAGE SPEED command. (Local road and freeway ramp speeds are fixed in the model.) Doing this will bypass the model default speed distribution. For example, if a user enters 50 mph as the freeway speed, then all VMT on all freeway links are assumed to be 50 mph. Because the effect of speed on emission rates is not linear, using such a single average speed would produce different emission results than using a VMT distribution across speeds that averages 50 mph.

MOBILE Default Distributions

Finally, users can rely entirely on MOBILE defaults for speed information. MOBILE6 will calculate emission factors based on a default distribution of VMT by speed bin and by hour. This default distribution is intended to be a national distribution representing all Federal-aid urbanized areas (areas with a population of 50,000 or more). It was developed using data from Chicago, Houston, Charlotte, Ada County (Boise, ID) and New York City regions. Thus, the MOBILE6 default distribution of VMT by speed bin may not be appropriate for small urban and rural areas.

For example, Table 3 shows the MOBILE6 default VMT distribution by speed at 5 pm. (The model has similar distributions for every hour of the day.) More than 30 percent of freeway VMT in this distribution occurs at speeds less than 42.5 mph, indicating significant congestion. This distribution would not be representative of a rural area with little peak-period freeway congestion.

¹² *Technical Guidance on the Use of MOBILE6.2 for Emission Inventory Preparation*, U.S. EPA, August 2004.

Table 3: Example of MOBILE6 Default Distribution of VMT by Speed Bin, 5 – 6 pm

Speed Bin (mph)	VMT Fraction	
	Freeway	Arterial
0.0 – 2.5	0.0156	0.0049
2.5 – 7.5	0.0411	0.0165
7.5 - 12.5	0.0225	0.0087
12.5 - 17.5	0.0199	0.0222
17.5 - 22.5	0.0284	0.0652
22.5 - 27.5	0.0316	0.1222
27.5 - 32.5	0.0500	0.2809
32.5 - 37.5	0.0488	0.0959
37.5 - 42.5	0.0446	0.2557
42.5 - 47.5	0.0555	0.0405
47.5 - 52.5	0.2223	0.0651
52.5 - 57.5	0.1092	0.0095
57.5 - 62.5	0.2957	0.0125
62.5 - 67.5	0.0147	0
Total	1.0	1.0

Source: *Development of Methodology for Estimating VMT Weighting by Facility Type*, U.S. EPA, Report Number M6.SPD.003, April 2001.

Use of Local Speed Data

Many of the methods described in this section require collection and processing of local data on observed speeds. It is important that users understand how to interpret specific speed databases because of the variety of methods used to report speeds. For example, pairs of in-road loop detectors provide instantaneous speeds of individual vehicles at a fixed location that may not be representative of overall speed distributions along the roadway segment. Average speeds may be calculated, as either arithmetic means or harmonic means (the inverse of the average of the inverses of observed speeds). For speed measurements at a specific location, these are sometimes referred to, respectively, as “time-mean speed” and “space-mean speed.” The harmonic mean is generally preferred because the arithmetic mean provides a positively biased estimate. Arithmetic means from some other measurement methods (e.g., second-by-second recording in instrumented vehicles) can be used to provide unbiased space-mean speeds.¹³

¹³ This paragraph adapted from *Guidance for the Development of Facility Type VMT and Speed Distributions*, U.S. EPA, Report Number M6.SPD.004, February 1999.

3.3 METHODOLOGIES FOR ESTIMATING SPEED IN AREAS WITHOUT A TDF MODEL

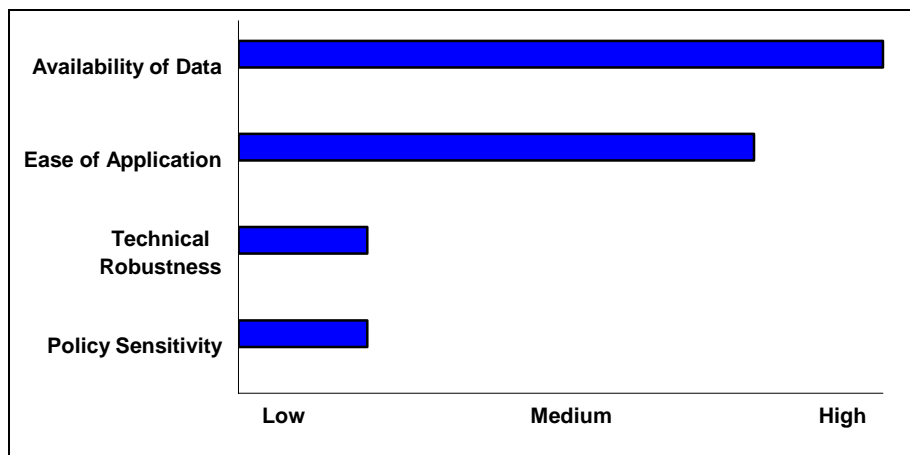
Areas that do not have a TDF model generally lack detailed information on the roadway network and associated traffic volumes. Therefore, many areas without a TDF model do not have the option of estimating speed on a large number of roadway segments as may be needed to determine the distribution of VMT by speed. These areas often must rely on traffic volume and roadway capacity data for a subset of roadway segments in order to estimate average speeds by functional class. Some areas, however, maintain a database or spreadsheet of all roadway segments (except local streets) even though they do not have a calibrated TDF model.

The simplest option for estimating speed (Method 1) is to estimate average speeds by functional class based on speed limits or observed speeds, without consideration of traffic volumes. This approach requires relatively little effort and little or no new data collection. However, it is insensitive to future changes in policy or traffic volumes. This simple method is typically adequate, however, when the area is estimating only direct PM emissions, since the PM exhaust emissions factors in the MOBILE6.2 model do not vary with speed. Note that although this method is more often applied in areas without a TDF model, it can also be applied by locations with a TDF model, particularly if the area is analyzing PM exhaust emissions.

Most regions without a TDF model estimate average speeds by considering traffic volumes and roadway capacities. Three such methods are the HERS model (Method 3), the BPR formula (Method 4), and the TTI method (Method 5). In theory, these methods can be applied to estimate speeds on every individual roadway link, although most regions without a TDF model estimate average speeds by functional class using aggregated volume and capacity information. Some areas use a combination of these approaches, such as a simple method to estimate speeds on lower functional class roadways (i.e., collectors and local roads) and a more complex approach for freeways and arterials.

ESTIMATING SPEED WITHOUT A TDF MODEL

Method 1: Use Observed Speeds and/or Speed Limits



Description This methodology makes assumptions about average speeds by facility type based on posted speed limits and/or observed speeds. No analysis of link-specific traffic volumes or speeds is involved.

Method Applicability This method is most applicable for areas that lack roadway volume and capacity information. This method would be most appropriate for rural areas that expect to see no change in travel speeds over time. Some areas use this method to estimate average speed on a particular facility type (such as collectors and local roads) and use more accurate methods to estimate speeds on other facility types.

Data Sources and Procedures *Speed Estimation*
A single average speed is estimated for each facility type, based on the posted speed limit, observed travel speeds, or professional judgment. No analysis of traffic volumes and capacity is used to determine speeds.

Because this method is relatively simplistic, it typically assumes no change in speed over time. Thus, the future year speeds by facility type are assumed to be identical to the base year speeds.

- Advantages**
- Simplicity of the approach.
 - Requires little or no new data collection.
 - Requires little effort by the analyst.
 - If based on observed speeds, likely to be more accurate than using MOBILE default speed information.

- Limitations**
- Accuracy is likely to be poor because observed speed data will reflect only a portion of roadway segments.
 - Does not account for effects of changes in VMT and congestion over time.

Example The Colorado DOT assumed an average speed of 35 mph for all arterials and 25 mph
Location for all collectors and local roads in Aspen for estimating PM-10 emissions in a conformity analysis conducted for State Highway 82 (Entrance to Aspen).

The Yuma MPO (Arizona) assumed an average speed of 10 mph for all unpaved roads for estimating PM-10 emissions in its 2003 conformity analysis.

References:

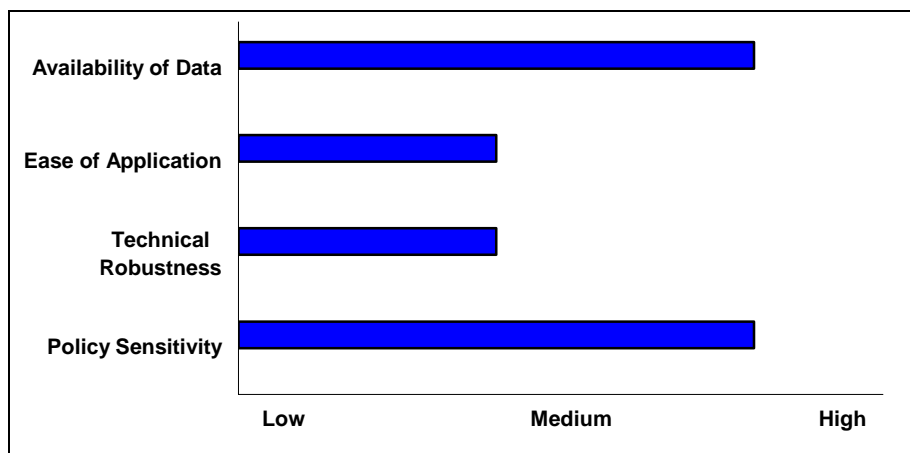
Colorado DOT, "Air Quality Analysis, A Technical Report to the State Highway 82 Entrance to Aspen Environmental Impact Statement," July 7, 1995.

Yuma MPO, "2003 Air Quality Conformity Procedures Outline", draft adopted June 2003.

Lima & Associates "Vehicle Particulate Emissions Analysis" prepared for ADOT, and Yuma MPO, May 2002.

ESTIMATING SPEED WITHOUT A TDF MODEL

Method 2: Use HERS Model at Statewide Level



Description This methodology makes use of the Highway Economic Requirements System (HERS) model to estimate speed. HERS is a computer model developed by FHWA to analyze the effects of alternative funding levels on highway performance. HERS uses HPMS data to analyze the benefits and costs of alternative improvements. HERS computes vehicle speeds for the purpose of determining link travel time and vehicle operating cost, and these speed estimates can be used for calculating emissions. The latest version of the HERS model has a much more accurate speed estimation methodology than the HPMS Analytical Process, which was used by FHWA until the mid-1990s.

The original HERS model was developed for use at national scale. The model can now be customized for use at the statewide level (called HERS-ST). For more information, see FHWA, *HERS-ST v20: Highway Economic Requirements System - State Version Technical Report*, November 17, 2003. Available online at <http://isddc.dot.gov/OLPFiles/FHWA/010945.pdf>.

Method Applicability Most applicable for states that desire statewide speed estimates for all rural roads, by functional class. Method does not produce regionally specific speed estimates. Method may not produce accurate results for urban roadway classes in small urban areas.

Data Sources and Procedures *Speed Estimation*
The HERS model is set up and run for the entire state. HERS uses HPMS data as inputs. HPMS data includes only a sample of roadway segments, and the sample size is too small in most cases to produce valid results at the county-level. Thus, the model should be run with the intent of estimating speed by roadway functional class for the entire states.

The latest version of HERS (version 3.54) uses a simplified version of the “Aggregate Probabilistic Limiting Velocity Model” (APLVM) in order to calculate free-flow speeds on each link. The model then applies algorithms to incorporate the effects of grades, traffic-control devices, and congestion on vehicle speed.

For each roadway section, HERS models speed by vehicle type in each direction of travel. Overall average speed per section is aggregated from the speeds of the individual vehicle types. Average link speeds are a by-product of the HERS model rather than one of the standard outputs. Link average speeds are then grouped by the 12 HPMS functional classes (six urban and six rural) for the entire state and averaged by facility type.

Because HERS is designed to evaluate future investment scenarios, it estimates both current and future speeds, based on current and forecasted traffic volumes. If the HERS traffic volume forecasts are consistent with the information used to forecast VMT for emissions purposes (Section 2), then the HERS speed forecasts would be acceptable for emissions estimation purposes. If not, then an alternative method may be needed to estimate future speeds.

- Advantages**
- Uses existing HPMS data. Does not require new data collection.
 - Speed calculation algorithm considered accurate.
 - Accounts for future congestion impacts on speed.
- Limitations**
- Speeds may not be very sensitive to specific local/regional conditions.
 - Running the HERS-ST model can require substantial set-up time if the state is not already using the model.
- Example Location** Kentucky used this method to estimate statewide average speeds by functional class in rural areas. These values were used to estimate NO_x and VOC emissions in two isolated rural areas.

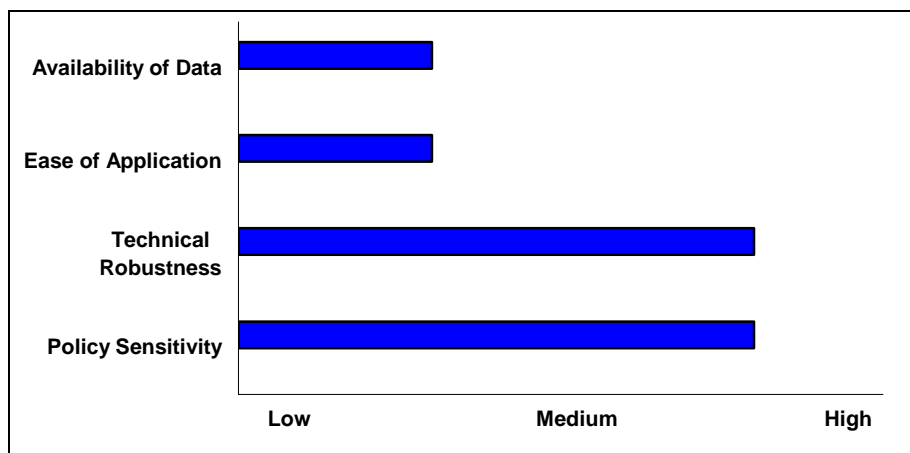
Website: http://transportation.ky.gov/Multimodal/Air_Quality.asp

Reference:

Bostrom, Rob and Jesse Mayes, "Highway Speed Estimation for MOBILE6 in Kentucky," Kentucky Transportation Cabinet, 2002.

ESTIMATING SPEED WITHOUT A TDF MODEL

Method 3: Use BPR Formula or Variation



Description This methodology estimates speed using some form of the “BPR formula,” which is based on the volume/capacity (V/C) ratio and the free-flow speed. The original BPR formula was developed in the 1960s. More recent modifications to the formula parameters can improve accuracy of speed estimates. For detailed information on the BPR formula and related methods, refer to NCHRP Report 387, *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications* and the Appendix.¹⁴

Method Applicability This method is applicable for regions that have volume and capacity data by roadway segment, or can accurately estimate aggregate volume and capacity by facility type. This method is appropriate for areas with roadway congestion that are estimating NO_x, VOC, or CO emissions.

Data Sources and Procedures This method can be applied to determine speeds on individual links, which can then be used to estimate a VMT distribution by speed bin for MOBILE6 input. Alternatively, this method can be applied to average VMT and capacity values in order to determine an average speed by functional class.

BPR-type formulas require three inputs: free-flow speed, roadway capacity, and traffic volume. Traffic volume information is developed as described in Section 2 of this report. The accuracy of this method is highly dependent on the accuracy of the capacity and free-flow speed inputs. Procedures for developing these two inputs are described below as well as in the Appendix of this report, followed by procedures for applying the BPR formula.

Free-flow speed estimation

NCHRP Report 387 recommends estimating free-flow speed by link using the following separate equations for unsignalized and signalized facilities.

¹⁴ Additional detail on BPR formulas and related methods can be found in the Transportation Research Board’s 2000 *Highway Capacity Manual*.

[Note: additional discussion of free flow speed estimation techniques can be found in the Transportation Research Board's 2000 *Highway Capacity Manual*.]

Free-flow speed equation for unsignalized facilities:

$$\begin{aligned} \text{Free-flow speed} &= 0.88 * S_p + 14 \\ &\text{(High-speed facilities have posted speed} > 50 \text{ mph)} \\ \text{Free-flow speed} &= 0.79 * S_p + 12 \\ &\text{(Low-speed facilities have posted speed} \leq 50 \text{ mph)} \end{aligned}$$

where S_p = posted speed limit in mph

Free-flow speed equation for signalized facilities:

$$\text{Free-flow speed} = \frac{L}{L/S_{mb} + N * (D/3600)}$$

where: L = length of facility (in miles)
 S_{mb} = mid-block free-flow speed = $0.79 * \text{posted speed} + 12$ mph
 N = number of signalized intersections on length, L
 D = average delay per signal

$$D = DF * 0.5 * C(1-g/C)^2$$

where: D = total signal delay per vehicle (sec)
 g = effective green time (sec)
 C = cycle length (sec)

(Default values for these parameters are provided in the Appendix.)

When using these equations to estimate free-flow speed on a large number of links, it is typically impractical to apply the equations individually for each link. Instead, the equations are used to develop look-up tables of free-flow speeds by facility type and area type. The look-up table is then used to quickly assign free-flow speeds to each link. The Appendix includes an example of such a look-up table.

Free-flow speeds can be determined using other more simplistic methods. Some regions estimate flow speeds by facility type based on the posted speed limit. In other cases, areas add or subtract a fixed amount to/from the speed limit (e.g., speed limit plus 5 mph for highways) or multiply the speed limit by a fixed percentage (e.g., 62% of speed limit for collectors). These simple adjustments to posted speed limits are usually based on a limited sample of measured local speeds that are available for the desired roadway classification. When using these rules for estimating free-flow speeds, the equations often differ based on area type (e.g., CBD, rural, etc.). Other regions estimate free-flow speeds by facility type using observations of off-peak speeds.

Roadway capacity estimation

NCHRP Report 387 recommends a set of equations for estimating capacity that are

based on the 1994 *Highway Capacity Manual*. There are separate equations for freeways, 2-lane unsignalized roads, and signalized arterials.

[Note: a more detailed discussion of capacity estimation techniques can be found in the Transportation Research Board's 2000 *Highway Capacity Manual*.]

Capacity equation for freeways and unsignalized multilane roads:

$$\text{Capacity (vph)} = \text{Ideal Cap} * N * F_{hv} * PHF$$

Where: *Ideal Cap* = ideal capacity in passenger cars per hour per lane (pcphpl)

N = number of through lanes

F_{hv} = heavy vehicle adjustment factor

PHF = peak-hour factor

Capacity equation for two-lane unsignalized roads:

$$\text{Capacity (vph)} = \text{Ideal Cap} * N * F_w * F_{hv} * PHF * F_{dir} * F_{nopass}$$

Where: *Ideal Cap* = ideal capacity in pcphpl

N = number of through lanes

F_w = lane width and lateral clearance factor

F_{hv} = heavy vehicle adjustment factor

PHF = peak-hour factor

F_{dir} = directional adjustment factor

F_{nopass} = no-passing zone factor

Capacity equation for signalized arterials:

$$\text{Capacity (vph)} = \text{Ideal Cap} * N * F_{hv} * PHF * F_{park} * F_{bay} * F_{CBD} * g/C * F_c$$

Where: *Ideal Cap* = ideal capacity in pcphpl

N = number of through lanes

F_{hv} = heavy vehicle adjustment factor

PHF = peak-hour factor

F_{park} = on-street parking adjustment factor

F_{bay} = left turn bay adjustment factor

F_{CBD} = central business district adjustment factor

g/C = ratio of effective green time per cycle

F_c = optional user-specified calibration factor

The parameters to use in these equations are provided in the Appendix.

As with free-flow speeds, it is usually impractical to apply the capacity equations individually for every link, so look-up tables are developed.

Computing average speed

The updated BPR formula is as follows:

$$s = \frac{s_f}{1 + a\left(\frac{v}{c}\right)^b}$$

where: s = predicted mean speed
 s_f = free-flow speed
 v = volume
 c = practical capacity
 $a = 0.05$ for facilities with signals spaced 2 mi apart or less
 $= 0.20$ for all other facilities
 $b = 10$

Many regions have modified the parameters a and b so that the formula calculates speeds that more closely reflect observed local speeds. The original BPR formula uses $a = 0.15$ and $b = 4$. Other regions have used values of a as high as 1.0 and values of b as high as 11.

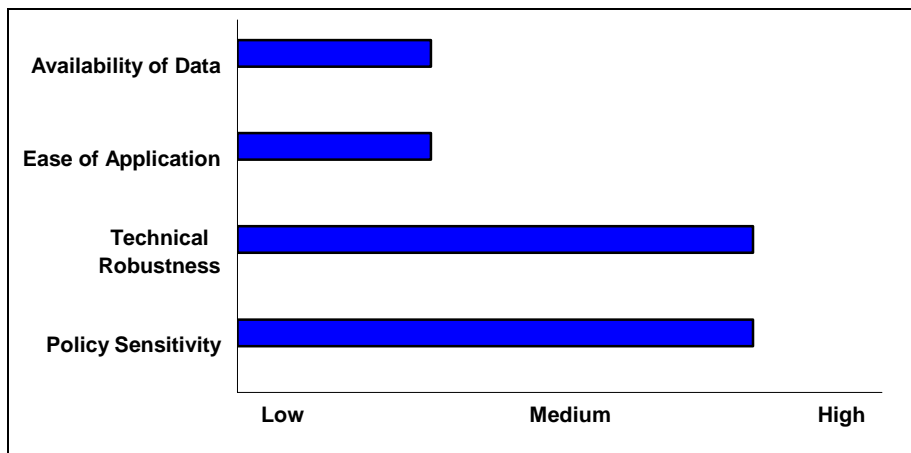
- Advantages**
- Able to produce highly accurate speed estimates if applied properly.
 - Accounts for future congestion impacts on speed.
- Limitations**
- In order to produce accurate speed results, requires accurate local information on capacity and free-flow speed. Use of default look-up tables for these values can lead to inaccurate speed estimates.
 - To apply this method for individual links requires detailed information regarding signalization characteristics, traffic characteristics, etc.
 - Method not accurate for V/C ratios over 1.0.
- Example Location** Ohio DOT used the original form of the BPR formula ($a = 0.15$ and $b = 4$) to estimate speed in rural areas not covered by a TDF model. To estimate free-flow speeds, Ohio DOT used the upper bound of the table provided in the HCM for each functional class.

Website: <http://www.dot.state.oh.us/urban/index.htm>
 (Speed forecasting procedures described under “documents” section)

References:
 Ohio DOT, “Technical Memorandum: Clinton County 2000-2003 STIP/TIP Emissions Estimate,” May 25, 1999.

ESTIMATING SPEED WITHOUT A TDF MODEL

Method 4: Use TTI Method



Description This methodology estimates aggregate average speeds by functional class, time-of-day period, and direction. The methodology uses Highway Performance Monitoring System (HPMS) data, equations to calculate delay and congested speed, and look-up tables for parameters based on the 1994 HCM. For more information on this method, refer to Dresser, George B., and Dennis G. Perkinson, “Development of On-Road Mobile Source Emission,” Texas Transportation Institute, Paper prepared for the 10th Annual Emission Inventory Conference: Inventories for Rural Counties, May 2001.

Method Applicability This method is applicable for regions that have volume and capacity data by roadway segment, or can accurately estimate aggregate volume and capacity by facility type. This method is appropriate for areas with roadway congestion that are estimating NO_x, VOC, or CO emissions.

Data Sources and Procedures This method can be applied to determine speeds on individual links, which can then be used to estimate a VMT distribution by speed bin for MOBILE6 input. Alternatively, this method can be applied to average VMT and capacity values in order to determine an average speed by functional class. The procedure described below is to determine average speed by functional class.

This method requires estimation of traffic volume, free-flow speed, and roadway capacity, using HPMS data aggregated by area type and functional class.

Volume estimation

HPMS data is first separated into area types and roadway functional classifications. Area type is defined by population – rural (4,999 or less), small urban (5,000 to 49,999), and urban (50,000+). Functional classifications are based on the HPMS classes (Interstate, freeway, other principal arterial, minor arterial, major collector, minor collector, and local).

VMT by area/functional class is allocated into time periods. The four default time periods correspond to the AM peak (7:15 a.m. - 8:15 a.m.), mid-day (8:15 a.m. - 4:45 p.m.), the PM peak (4:45 p.m. - 5:45 p.m.), and overnight (5:45 p.m. - 7:15 a.m.). The

default allocation factors for these periods are, respectively, 0.1069, 0.5033, 0.1018, and 0.2880.

VMT by area/functional class and time period is further disaggregated by directional split. The default directional split is 60/40. VMT per time period is divided by centerline miles, yielding volume for each time period, each area type and functional class, and each direction.

Free-flow speed estimation

Free-flow speeds are estimated for each combination of area type and functional class. Default values are shown in the table below. Free-flow speeds are assumed not to vary by time-of-day period or direction.

Default values for free flow speed (mph)

HPMS Area Type	HPMS Roadway Functional Classification						
	Interstate	Freeway	Other				Local
			Principal Arterial	Minor Arterial	Major Collector	Minor Collector	
Rural	70	65	55	50	40	35	30
Small Urban	70	65	45	40	35	30	30
Urban	70	65	40	35	30	30	30

Roadway capacity estimation

Roadway capacity values are estimated based on the 1994 HCM. For all Interstates, the method uses a default capacity of 2,200 passenger cars per hour per lane (pcphpl). Freeways are assumed to have a default capacity of 2,100 pcphpl.

Other functional class roadways have traffic controls, so capacity is determined using the following equation:

$$C_i = S_i * (g_i/C)$$

Where: C_i = capacity of lane group i (vehicles per hour)

S_i = saturation flow rate of lane group i , vehicles per hour of effective green time (vphg)

g_i/C = effective green ratio for lane group i

Default values for effective green ratios (g_i/C) by HPMS roadway functional class

Principal Arterial	Minor Arterial	Major Collector	Minor Collector	Local
0.6	0.55	0.5	0.4	0.3

Saturation flow rate is calculated using the following equation:

$$S = f_w * f_{hv} * f_g * f_p * f_{bb} * f_a * f_n * f_{lt}$$

Where: S = saturation flow rate adjustment factor (rounded to 2 decimal places)

f_w = lane width adjustment factor (default is 12-foot lanes)

f_{hv} = heavy vehicle adjustment factor (default is 5%)

- f_g = approach grade factor (default is 1, level terrain)
- f_p = parking lane adjustment (none for rural, 1 per hour for urban)
- f_{bb} = bus blocking factor (none for rural, 10 per hour for urban, mid-point for small urban areas)
- f_a = area type adjustment (0.9 for urban area, 1.0 for all other areas)
- f_{rt} = right turn adjustment factor (shared lane for right turns for all area types, high pedestrians crossing for urban areas, moderate for small urban areas, and low for rural)
- f_{lt} = left turn adjustment factor (exclusive left turn lanes and protected phasing for rural areas, shared left turn lanes and protected plus permitted phasing for urban areas, mid-point for small urban areas)

If possible, these parameters should be developed using local estimates, for each combination of area type and functional class. Otherwise, the method suggests use of the default values in the table below.

Default saturation flow rate adjustment factors by area type

Area Type	f_w	f_{hv}	f_g	f_p	f_{bb}	f_a	f_{rt}	f_{lt}
Rural	1	0.95	1	1	1	1	0.98	0.95
Small Urban	1	0.95	1	0.98	0.98	1	0.94	0.90
Urban	1	0.95	1	0.95	0.96	0.90	0.90	0.85

Using the default adjustment factors results in the following default values for hourly lane capacity, by area type and functional class.

Default hourly lane capacities (vehicles per hour per lane)

HPMS Area Type	HPMS Roadway Functional Classification						
	Other		Principal Arterial	Minor Arterial	Major Collector	Minor Collector	Local
	Interstate	Freeway					
Rural	2,200	2,100	1,003	920	836	669	502
Small Urban	2,200	2,100	878	805	732	585	439
Urban	2,200	2,100	673	617	561	448	336

The hourly lane capacity values are then used to estimate aggregate capacity by time-of-day period. To do this, the lane capacities are multiplied by the number of lanes associated with each area type/functional class (lane miles divided by centerline miles). Hourly roadway capacities are then typically multiplied by the number of hours in the time period to produce time period capacities. This procedure is performed for each combination of time period, roadway functional classification, and area type. (Capacity is the same for each direction and time period.)

Computing average speed

Calculation of average speed requires the aggregate volume and capacity as described above and the free-flow speed values. The calculation of speed uses a formula originally developed by the North Central Texas Council of Governments for the Dallas/Fort Worth area. The procedure involves calculating delay using the following equation:

$$Delay = \text{Min} \left[A e^{B \left(\frac{V}{C} \right)}, M \right]$$

Where: *Delay* = congestion delay (in minutes/mile);
A & *B* = volume/delay equation coefficients;
M = maximum minutes of delay per mile; and
V/C = time-of-day directional volume/capacity ratio.

Parameters:

Facility Category	Parameter		
	A	B	M
High Capacity Facilities (>3,400 vehicles/hour, e.g. Interstates and Freeways)	0.015	3.5	5
Low Capacity Facilities (<3,400 vehicles/hour, e.g. Arterials, Collectors, and Locals)	0.05	3	10

Congested speeds can then be calculated as follows:

$$Congested_speed = \frac{60}{\frac{60}{Freeflow_speed} + Delay}$$

The result is an estimate of average speed for each combination of area type, functional class, and time-of-day period. These values can then be used to determine VMT distributions by speed for the MOBILE6 inputs.

- Advantages**
- Can produce highly accurate speed estimates.
 - Accounts for future congestion impacts on speed.
 - If using the default look-up tables for free-flow speed and capacity, this method can be applied relatively quickly, without major new data collection.
- Limitations**
- In order to produce accurate speed results, requires accurate information on capacity and free-flow speed.
 - To apply this method for individual links, requires detailed information regarding signalization, traffic characteristics, etc.

Example Location North Carolina used this method to estimate VOC and NO_x emissions in donut areas (part of a metropolitan non-attainment area but outside MPO boundaries). North Carolina used this method to estimate average speeds by area type (rural, small urban, urban) and functional class. North Carolina also tested the BPR formula and another speed formula (the Greenshields method), but found that the TTI method produced speed estimates that most closely match observed values.

References:

North Carolina DOT, Davidson County, and the North Carolina Department of Environment, "Emissions Analysis Report for the Transportation Plan for Rural Portion of Davidson County," September 27, 2002.

Rural Conformity Spreadsheet PowerPoint Presentation, Behshad Norowzi, North Carolina Department of Transportation, July 2004.

3.4 METHODOLOGIES FOR ESTIMATING SPEED IN AREAS WITH A TDF MODEL

The use of a TDF model requires development of a computerized roadway network, typically representing all major roadway links in a region. The model then estimates traffic volumes on these represented links, for a base year and forecast years. Thus, areas that use a TDF model have volume and capacity information for all major roadway links, and can use this information to estimate speeds for the purpose of estimating emissions.

This section discusses methods for estimating speeds for links covered by the TDF model, as well as methods for estimating speeds for links outside of the TDF model coverage (i.e., donut areas beyond the MPO modeling area).

3.4.1 Methodologies to Estimate Speeds in Model Area

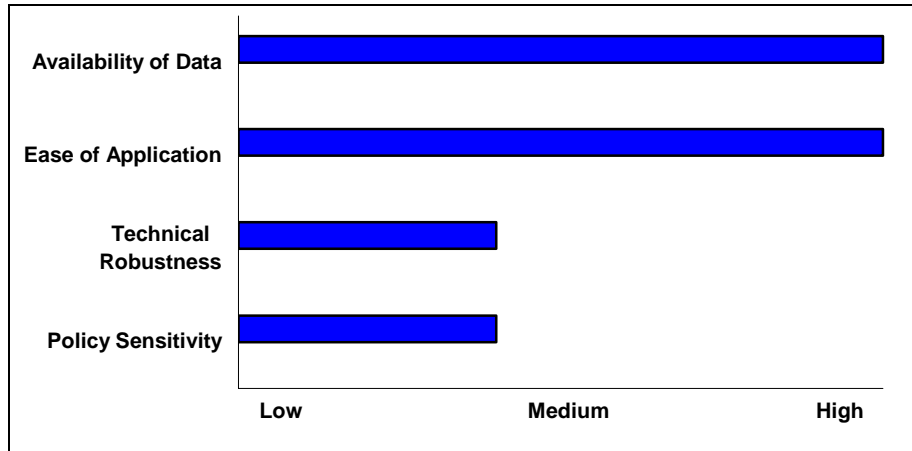
A TDF model estimates traffic speed on each link as part of the network assignment process. The assignment process typically determines the route between an origin node and a destination node that results in the shortest travel time. The assignment process is iterative – all trips are first routed based on free-flow travel times, then link travel times are recalculated based on congestion delay, then trips are re-routed based on the new link travel times, and so on until the process reaches equilibrium.

TDF models are typically calibrated so that they closely match observed traffic volumes, but not traffic speeds. Because TDF models must quickly calculate speeds for thousands of links, they use relatively simple equations, such as the BPR formula, and generally do not account for detailed facility or traffic characteristics in the speed calculation. TDF models calculate speeds only for the purposes of facilitating the traffic assignment process, not for the purpose of emissions estimation or other planning practices. Thus, the TDF model speeds may or may not accurately reflect current and future speeds.

Some regions use TDF model speeds directly for developing emission factors (Method 1). Other regions perform adjustments of TDF model speeds to improve accuracy (Method 2), or use a post-processor to estimate speeds rather than use TDF model speeds (Method 3). Use of a post-processor typically relies on methods such as the BPR formula described in Section 3.3.

ESTIMATING SPEED WITH A TDF MODEL: ANALYSIS IN AREA COVERED BY MODEL

Method 1: Use TDF Model Outputs



Description This methodology makes use of TDF model outputs to develop the speed inputs for the MOBILE model. TDF models estimate traffic speeds on each link for the purposes of assigning trips to the network. These traffic speeds can be used to develop emission factors, either by estimating a VMT distribution by speed or by estimating average speeds by facility type.

Method Applicability This method is applicable for areas that have a validated TDF model, but do not have observed traffic speed data for the purposes of modifying inaccurate model speeds and do not have the resources for more detailed and accurate speed estimation methods.

Data Sources and Procedures If the TDF model speeds are determined to be acceptable, link-level speeds can be processed for developing emissions factors in the MOBILE6 model. The best option is to determine the distribution of VMT by speed bin for each facility type. Link volumes are multiplied by link length to calculate link VMT. For each facility type, link VMT is then allocated to speed bins, and the distribution of this VMT become a MOBILE6 input.

Alternatively, links can be grouped by facility type, and an average speed (weighted by VMT) calculated for each facility type. The same process is applied for base year speeds and forecast year speeds.

- Advantages**
- For regions with a calibrated TDF model, this method requires little additional resources or effort.
 - Accounts for future changes in traffic volumes and congestion.

- Limitations**
- TDF models are not designed to accurately calculate speeds. Actual speeds may differ significantly from modeled speeds.

Example Location Butte County, California used this method to develop emission factors for NO_x, VOC, and CO. Madera County, California used this method to develop emission factors for NO_x, VOC, and PM-10. Both counties used TDF model output to group link VMT by speed for the purposes of estimating a VMT distribution by speed bin.

Bannock County, Idaho used this method to estimate average speeds by facility type for the purposes of developing PM-10 emission factors in MOBILE6.2.

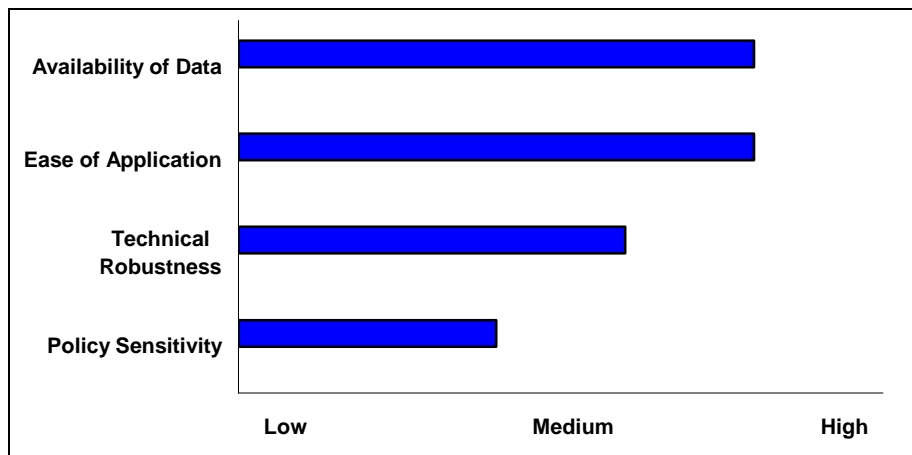
Resources:

Butte County Association of Governments, “Draft Air Quality Conformity Determination for the 2001 Regional Transportation Plan And Adopting Resolution”, Adopted April 26, 2001.

Earth Matters, “San Joaquin Valley Air Quality Modeling Procedures – 2001 RTPs and TIPs,” 2001.

ESTIMATING SPEED WITH A TDF MODEL: ANALYSIS IN AREA COVERED BY MODEL

Method 2: Use TDF Model Outputs with Adjustments where Model Values Appear Unreliable



Description This method relies on TDF model speeds where they appear accurate and makes adjustments to the model speeds where they appear inaccurate when compared against a sample of observed traffic data.

Method Applicability This method is applicable for areas that have a validated TDF model and have some observed traffic speed data for the purposes of modifying inaccurate model speeds.

Data Sources and Procedures This method first requires a review of TDF model output speeds to assess their accuracy. Data on observed traffic speeds should be organized by link, and then compared to the modeled speeds on those links. Modeled speeds may be unacceptable for all facility types, or may be unacceptable for only selected facility types (e.g., arterials) or for selected area types (e.g., CBD).

In the case of facility/area types for which model speeds appear accurate, these speeds are used as described in Method 1. The best option is to determine the distribution of VMT by speed bin for each facility type. Alternatively, links can be grouped by facility type, and an average speed (weighted by VMT) calculated for each facility type. The same process is applied for base year speeds and forecast year speeds.

In the case of facility/area types for which model speeds are inaccurate, a variety of approaches can be taken. In some cases, modeled speeds may simply be scaled up or down to better reflect observed speeds. Speeds can also be estimated by applying a formula or look-up table based on the V/C ratio (see Method 3 below). The same process is applied for base year speeds and forecast year speeds.

- Advantages**
- For regions with a calibrated TDF model, this method requires little additional resources or effort.
 - This method makes use of TDF model speeds where they appear accurate, which can save time and resources as compared Method 3 (below).

- Limitations**
- Modeled speeds may accurately reflect base year observed speeds, but may not accurately estimate future year speeds.
 - If modeled speeds are adjusted up or down to match base year observed speeds without consideration of V/C ratio, the method may be inaccurate for estimating future speeds.

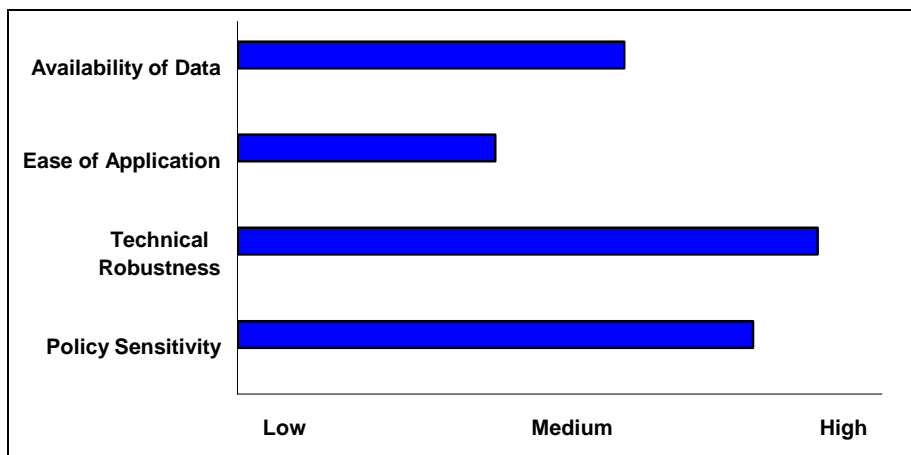
Example Location A variation of this method was used to estimate NO_x and VOC emissions in Parkersburg, West Virginia (Wood County). A review of TDF model speeds revealed that the model was overestimating speeds on local roads. For urban local roads, the MOBILE6 local road default speed was used. For rural local roads, an average of the model speed and the MOBILE6 default speed was used.

References:

Wilbur Smith Associates, "Appendix F – Air Quality Conformity Analysis" from the *Wood-Washington 20 Year Multimodal Transportation Plan*, January 2004.

ESTIMATING SPEED WITH A TDF MODEL: ANALYSIS IN AREA COVERED BY MODEL

Method 3: Use Formula and/or Lookup Tables to Estimate Speed Based on Modeled V/C Ratio



Description This method makes use of the link-level volume and capacity information from the TDF model to estimate speeds, typically using some form of the BPR formula. The TDF model speeds are not used. This is the method employed by most large urban areas when estimating emissions. (For detailed information on this method, refer to NCHRP Report 387, *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications and Travel Model Speed Estimation and Post Processing Methods for Air Quality Analysis*, Federal Highway Administration, 1997; see Resources information for web links).

Method Applicability This method is applicable for areas that have a validated TDF model, have observed traffic speed data, and have sufficient resources to apply more detailed and accurate speed estimation methods.

Data Sources and Procedures The method estimates speed using some form of the BPR formula, which is based on the volume/capacity (V/C) ratio and the free-flow speed. BPR-type formulas require three inputs: free-flow speed, roadway capacity, and traffic volume. The accuracy of this method is highly dependent on the accuracy of the capacity and free-flow speed inputs. The development of these inputs is discussed under Method 4 in Section 3.3 and in the Appendix of this report. It also is reviewed below.

Because most TDF models are run for a 24-hour period or for peak and off-peak periods, this method can be used to estimate hourly speeds if this level of detail is desired for MOBILE6 input. To do this, link-level volumes are distributed by hour of day, based on distribution fractions typically developed from local traffic count data. The hourly VMT on each link is calculated by multiplying link volume by link length. Link speeds are estimated based on the V/C ratio, using the BPR formula, look-up tables, or other methods. A VMT distribution by speed bin then can be calculated for each hour of the day, by facility type.

Free-flow speed estimation

NCHRP Report 387 recommends estimating free-flow speed by link using separate equations for unsignalized and signalized facilities. These equations are presented in the Appendix.

Many regions estimate free-flow speeds based on look-up tables developed from default values in the *Highway Capacity Manual*, NCHRP Report 387, or other sources.

Some regions estimate free-flow speed by facility type using simplistic methods based on the posted speed limit, such as adding or subtracting a fixed amount to/from the speed limit. For example, one region used the speed limit plus 5 mph for highways based on typical observed speeds. Another region multiplied the speed limit for each functional classification by a fixed percentage (e.g., 62% of speed limit for collectors) developed from observed speeds. When using these rules for estimating free-flow speeds, the equations often differ based on area type (e.g., CBD, rural).

Other regions estimate free-flow speeds by facility type using observed off-peak speeds.

Roadway capacity estimation

NCHRP Report 387 recommends a set of equations for estimating capacity that are based on the 1994 *Highway Capacity Manual*. There are separate equations for freeways, 2-lane unsignalized roads, and signalized arterials. These equations are presented in the Appendix to this report.

Many regions estimate roadway capacity based on look-up tables developed from default values in the *Highway Capacity Manual*, NCHRP Report 387, or other sources.

Computing average speed

A variety of equations are used to estimate speeds. The most common is the BPR formula. The updated BPR formula is as follows:

$$s = \frac{s_f}{1 + a\left(\frac{v}{c}\right)^b}$$

where: *s* = predicted mean speed

s_f = free-flow speed

v = volume

c = practical capacity

a = 0.05 for facilities with signals spaced 2 mi apart or less

= 0.20 for all other facilities

b = 10

Many regions have modified the parameters *a* and *b* so that the formula calculates speeds that more closely reflect observed local speeds. The original BPR formula uses *a* = 0.15 and *b* = 4. Other regions have used values of *a* as high as 1.0 and

values of b as high as 11.

- Advantages**
- Can produce highly accurate speed estimates if applied properly.
 - Accounts for future congestion impacts on speed.
- Limitations**
- In order to produce accurate speed results, requires accurate local information on capacity and free-flow speed. Use of default look-up tables for these values can lead to inaccurate speed estimates.
 - To apply this method for individual links, requires detailed information regarding signalization characteristics, traffic characteristics, etc.

Example Location Ohio DOT uses this method to estimate speeds for small urban areas with TDF models. The TDF model output is used to determine a V/C ratio for each link. Speeds are then estimated using look-up tables taken from the *Highway Capacity Manual*.

Website: <http://www.dot.state.oh.us/urban/index.htm>

(Speed forecasting procedures described under “documents” section)

References:

“Technical Memorandum: Clinton County 2000-2003 STIP/TIP Emissions Estimate,” Ohio DOT, May 25, 1999.

Statewide Travel Time Study, Gregory T. Giaimo, Ohio DOT, May, 2001.

3.4.2 Methodologies to Estimate Speeds in Donut Areas not covered by TDF Model

In metropolitan areas that have a TDF model, there may be “donut” areas that are not covered by the model. These areas often lack detailed information on the roadway network and associated traffic volumes. Therefore, to estimate speeds in these areas, the methods presented in Section 3.3 (areas without a TDF model) can be used. Similar to Section 3.3, average speeds by functional class often must be estimated based on a subset of roadway segments. In some case of donut areas, however, output from a nearby area with a TDF model may be available to provide region-specific speed data to help estimate donut area speeds.

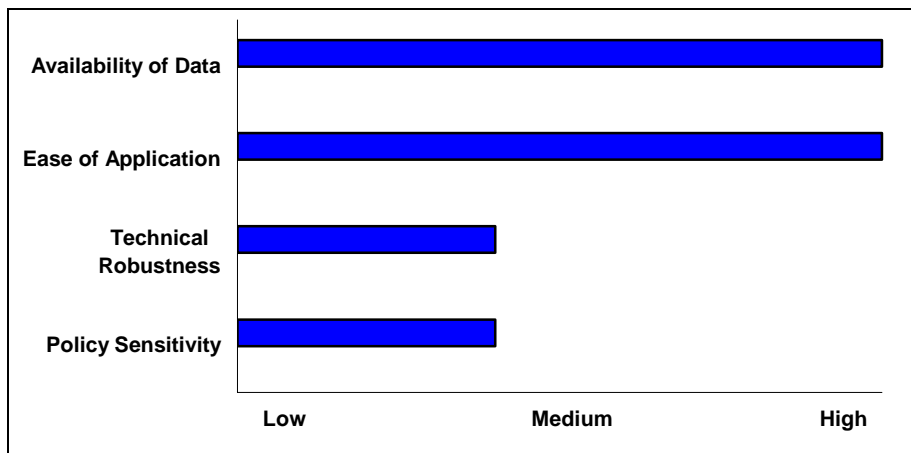
Following are the methods that have been identified in practice to estimate speeds in donut areas not covered by a TDF model, which rely to some extent on data from the TDF model:

- Method 1: Using Speeds from Modeled Area by Functional Class
- Method 2: Using a Mix of Speeds data from Statewide Model and from MPO Model

In addition, methods that are applicable to areas without a TDF model (see Section 3.3) can also be applied in donut areas, such as use of observed speeds and/or speed limits, or use of a formula and/or lookup tables.

ESTIMATING SPEED WITH A TDF MODEL: ANALYSIS IN AREA NOT COVERED BY MODEL

Method 1: Use Speeds from Modeled Area by Functional Class



Description This method assumes that TDF model speeds apply to the non-modeled donut areas.

Method Applicability This method is most applicable if little or no roadway traffic volume and capacity information is available for the donut area.

Data Sources and Procedures To apply this method, the speeds generated from the TDF model are used for the donut area. If the region uses the TDF model to estimate average speeds by functional class, then these average speeds are used for the VMT by functional class in the donut area. If the region uses the TDF model to develop a VMT distribution by speed bin, this distribution can be applied to the VMT in the donut areas.

Advantages

- For regions with a calibrated TDF model, this method requires little additional effort and no new data collection.
- This method is likely to be more accurate than using MOBILE default speeds.

Limitations

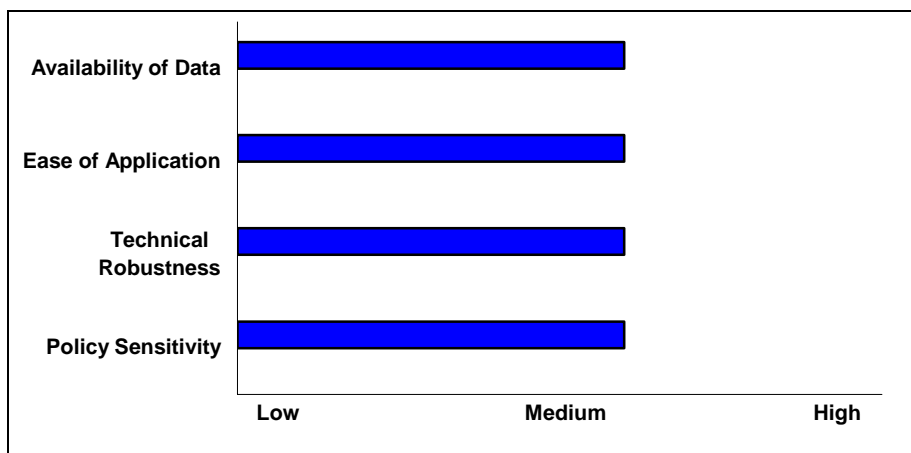
- TDF models are not designed to accurately calculate speeds. Actual speeds may differ significantly from modeled speeds.
- Travel speeds in donut areas (often predominantly rural) may differ significantly from travel speeds in the area covered by the TDF model (which are predominantly urban).

Example Location The Kentucky Transportation Cabinet (KYTC) has used this method to estimate emissions in several donut areas. Average speeds by functional class from the TDF model were assumed to apply to the entire nonattainment or maintenance area, including the donut area.

References: M.L. Barrett, R.C. Graves, D.L. Allen, J.G. Pigman, G. Abu-Lebdeh, L. Aultman-Hall, S.T. Bowling, Analysis of Traffic Growth Rates, University of Kentucky Transportation Center, August 2001.

ESTIMATING SPEED WITH A TDF MODEL: ANALYSIS IN AREA NOT COVERED BY MODEL

Method 2: Use Mix of Speeds from Statewide Model and from MPO Model



Description This method involves combining speed results from both a statewide travel model and the MPO’s TDF model. A statewide model generally provides broad geographic coverage (including coverage of the donut area) but relatively sparse network detail. The MPO TDF model provides more extensive network detail, but does not cover the donut area.

Method Applicability This method is applicable for a county (or other geographic area) that contains both a donut area covered by a statewide travel model and an urbanized area covered by a TDF model.

Data Sources and Procedures To apply this method, the statewide model is used to determine speeds by link for the donut area. The metropolitan area TDF model is used to determine speeds by link for the modeled areas within the same county (i.e., for the links contained within both TDF models, speeds are based on the metropolitan area TDF model). Speeds from the two models are then combined, weighted by VMT, and averaged by functional class. The resulting average speeds by functional class are used for the entire county (both modeled and non-modeled areas).

Local roads are not covered by statewide models. To estimate speeds for local roads in the donut area, an average local road speed is calculated for the area covered by the TDF model.

- Advantages**
- If an area has both a statewide model and an MPO TDF model, this method makes use of both models, which can improve accuracy as compared to using only one model.
 - Requires little additional effort and little or no new data collection.
 - Accounts for future congestion impacts on speed.

- Limitations**
- TDF models are not designed to accurately calculate speeds. Actual speeds may differ significantly from modeled speeds.
 - Travel speeds in donut areas (often predominantly rural) may differ significantly from travel speeds in the area covered by the TDF model (which are

predominantly urban). Therefore, using a single average speed by functional class for a county that contains both modeled area and donut area may introduce inaccuracies.

Example Location Michigan Department of Transportation (DOT) applied this method to estimate emissions in Allegan County. Michigan DOT maintains a statewide TDF model that includes 2,300 zones and a subset of roadway links. The MPO TDF model covers portions of Allegan County (City of Holland and three townships).

References:

Michigan DOT. "Allegan County Air Quality Conformity." Undated.

Michigan DOT, Travel Demand Analysis Section. "Technical Documentation of the Procedures Used to Develop VMT and Speed Estimates for Michigan Non-Attainment Counties Containing a Modeled Urban Area." 1995.

4 OTHER FACTORS: SAMPLE TECHNIQUES TO IMPROVE UPON MOBILE DEFAULTS

4.1 BACKGROUND

The MOBILE6 model (and EMFAC) takes into account a number of factors in estimating emission rates. In addition to vehicle speeds, important factors that influence emission rates include: the mix of vehicles that contribute to VMT, the age distribution of the vehicle fleet, the mix of VMT by type of roadway, and the existence and type and scope of inspection and maintenance (I/M) programs in place.

The MOBILE model contains default values for many of these factors, which may be used for simplicity. However, the MOBILE defaults may not reflect local conditions, and small urban and rural areas may want to identify data and use approaches to improve upon default values. This section describes several approaches to potentially improve upon default values.

4.2 VMT MIX BY VEHICLE TYPE

The VMT fleet mix determines how the VMT is assigned to each vehicle type (or class). Emission factors across vehicle classes may vary widely (greater than a factor of 100), so that even small changes in fleet mix have the potential for large changes in emission totals. Some of the small urban and rural areas have identified that getting the vehicle mix properly specified for their region was an important factor in helping their region meet conformity.

MOBILE6 users can enter information on VMT by vehicle class using the VMT FRACTIONS command. MOBILE6 uses 28 vehicle classes. However, for MOBILE6 VMT inputs, the 28 vehicle classes are consolidated into 16 vehicle classes shown in the table below. (The 28 classes are consolidated essentially by combining gasoline and diesel vehicles of a given class). Thus, the user inputs a set of 16 fractional values, representing the fraction of total VMT accumulated by each of the 16 combined vehicle types. The 16 values must sum up to 1.

Vehicle Classifications for MOBILE6 VMT Input

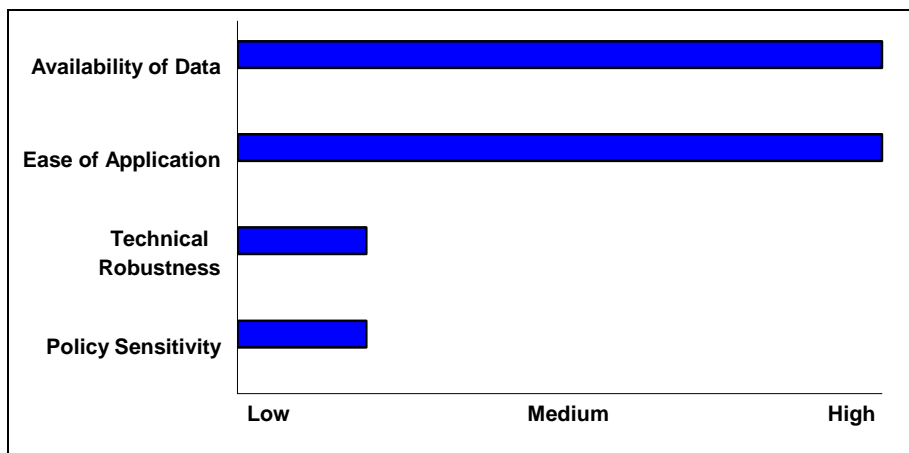
Number	Abbreviation	Description
1	LDV	Light-Duty Vehicles (Passenger Cars)
2	LDT1	Light-Duty Trucks 1 (0-6,000 lbs GVWR, 0-3,750 lbs LVW)
3	LDT2	Light-Duty Trucks 2 (0-6,000 lbs GVWR, 3,751-5,750 lbs LVW)
4	LDT3	Light-Duty Trucks 3 (6,001-8,500 lbs GVWR, 0-5,750 lbs ALVW)
5	LDT4	Light-Duty Trucks 4 (6,001-8,500 lbs GVWR, 5,751+ lbs ALVW)
6	HDV2b	Class 2b Heavy-Duty Vehicles (8,501-10,000 lbs GVWR)
7	HDV3	Class 3 Heavy-Duty Gasoline Vehicles (10,001-14,000 lbs GVWR)
8	HDV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001-16,000 lbs GVWR)
9	HDV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001-19,500 lbs GVWR)
10	HDV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501-26,000 lbs GVWR)
11	HDV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001-33,000 lbs GVWR)
12	HDV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001-60,000 lbs GVWR)
13	HDV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs GVWR)
14	HDBT	Transit and Urban Buses
15	HDBS	School Buses
16	MC	Motorcycles

Note: These class divisions are not likely those used in local vehicle registration systems or in reporting VMT data to the Federal Highway Administration's (FHWA) Highway Performance Monitoring System (HPMS), so care must be taken when relating vehicle types across these data sources.

If no information on VMT mix by vehicle class is entered, model default values are used. The MOBILE6 default values were developed from national-level vehicle registration data by age and class, as reported for July 1, 1996. EPA developed a methodology to convert the July 1, 1996 registration profile into a general registration distribution by age and by vehicle category for the 16 composite vehicle types and up to 28 individual vehicle classes. To forecast future changes, EPA evaluated general sales growth and vehicle scrappage trends for the total light-duty vehicle in-use fleet and the total heavy-duty vehicle in-use fleet, and made minor adjustments, where possible, to reflect some of the differences between vehicle categories.

ESTIMATING VMT MIX BY VEHICLE TYPE

Method 1: Use MOBILE6 Model Defaults



Description The MOBILE model requires estimates of a distribution of registered vehicles by age and vehicle category for current and future years. For MOBILE6 new national level vehicle registration data by age and class were developed for July 1, 1996. EPA developed a methodology to convert the July 1, 1996 registration profile into a general registration distribution by age and by vehicle category for some 16 composite (gasoline and diesel) vehicle types. To project future changes EPA evaluated general sales growth and vehicle scrappage trends for the total light-duty vehicle in-use fleet and the total heavy-duty vehicle in-use fleet, and made minor adjustments, where possible, to reflect some of the differences between vehicle categories.

Method Applicability This method is most applicable in a nonattainment or maintenance area where it is anticipated that the vehicle fleet mix is similar to the national default. This is most applicable in areas that parallel the national socioeconomic statistics. This assessment should include all on-road vehicles in the area including those outside the nonattainment or maintenance area if a considerable portion of vehicles in the on-road fleet come from outside the area.

Data Sources and Procedures This approach involves using the national default registration distribution that comes with the MOBILE6 model. A review of the national registration data should be made in order to verify the appropriateness of the national default data. This review could look at the most important class of emissions light-duty vehicles and heavy-heavy duty vehicles. Also, an assessment should be made as to the projected trends in sales growth and scrappage trends to determine if the default trends used in MOBILE6 are appropriate.

- Advantages**
- Uses a readily available, nationally recognized source of data that requires little effort for the user to apply.
 - Use of the national average facilities comparisons to other regions using the national averages for the fleet mix distribution.
 - The approach is simple to operationalize.

- Limitations**
- The area's VMT fleet mix may vary significantly from the national default. Thus, the approach may not provide a valid representation of the actual fleet mix.
 - The approach does not include local adjustments for changes in local scrappage or sales rates. Localized shifts in these trends may have substantial impact on emissions.

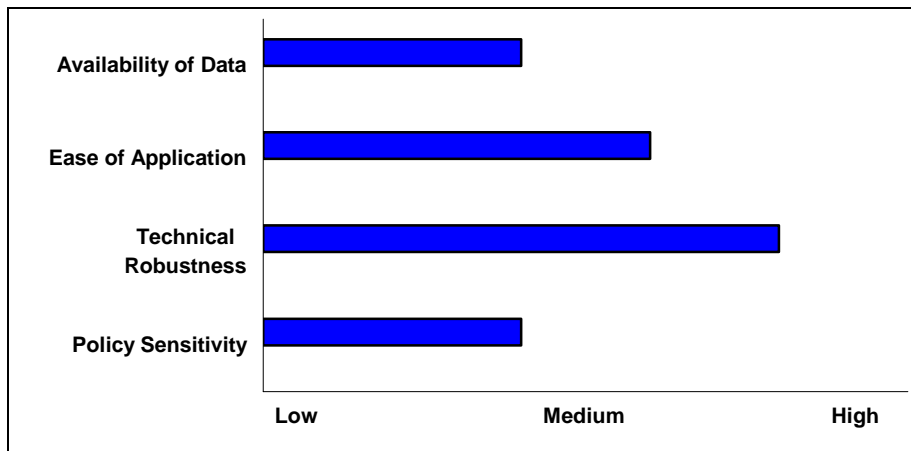
Example Location This methodology has been applied in Portneuf Valley, Bannock County, Idaho. It was suspected that the higher proportion of SUVs would be found in this county than the national default. A local vehicle count was conducted in the area, which verified that the national defaults were in the appropriate range for this category.

Resources:

Bannock Planning Organization, "FY2004 Draft Transportation Improvement Program Conformity Determination," August 15, 2003.

ESTIMATING VMT MIX BY VEHICLE TYPE

Method 2: Use Available Local Data and Maintain Constant Mix for Future Years



Description The MOBILE model requires estimates of a distribution of registered vehicles by age and vehicle category for current and future years. In this case, local registration and/or local traffic data are used to characterize the vehicle mix for the 16 composite MOBILE6 vehicle classes (or potentially the full 28 MOBILE6 categories), and this mix is assumed to hold constant over future years.

Method Applicability This approach is most applicable in areas where there are significant differences in the local vehicle fleet mix relative to the national average vehicle fleet mix, and where changes are not anticipated in the future. It is most applicable where the local traffic and/or registration data can be assembled and are representative of the nonattainment or maintenance area. Both traffic survey and registration data at the local level can be used to estimate vehicle fleet mix. However, if only local registration data are used, adjustments may be needed if a significant portion of on-road motor vehicles come from outside the nonattainment or maintenance area.

Method 2a: Use Local Vehicle Registration Data

Data Sources and Procedures This approach involves using local vehicle registration data. This is typically available at the county level, but may be possible to acquire at city or smaller scale from the state motor vehicle registrar office. The fleet mix should be representative of the vehicle mix over the small urban or rural area under question. If the pollutants of concern are ozone precursors then the data should reflect the July 1st date. For CO, the January 1st date should be used.

Also, an assessment should be made as to the projected trends in sales growth and scrappage trends to determine if the default trends used in MOBILE6 are appropriate when using this local vehicle registration data for baseline fleet composition. The extent to which the growth and scrappage trends diverge from the baseline is an important factor that will affect estimates of future year emission estimates.

Advantages ■ Uses locally specific registration data that is likely more representative of the local area than the national default.

- Requires minimal additional resources, particularly if data is readily available at the county or local level from the State department of motor vehicle registration.
- Recommended by EPA and is generally accepted as a viable approach.

- Limitations**
- Registration data may include vehicles owned, but not operated in the local area.
 - Registration data does not differentiate between seasonal usage differences in vehicles. For example, in some locations, light-duty trucks (LDTs) are operated more frequently in the winter months with the need for better traction in winter driving conditions; conversely light-duty vehicles (LDVs, or passenger cars) are used in summer months when driving conditions are less demanding.
 - Does not include local adjustments for changes in local scrappage or sales rates. Localized shifts in these trends may have substantial impact on emissions.

Example Location This methodology has been applied in a number of counties in Pennsylvania. The distributions were developed for July 1st and reflect the development of the fleet mix for the group of 16 composite MOBILE6 vehicle types. However, Pennsylvania elected not to use the heavy-duty vehicles registration data as they were limited and because much of Pennsylvania’s HHDDV traffic is through traffic. Pennsylvania used the MOBILE6 defaults for HHDDV. This approach was also used in Missoula County, Montana with the same mix in future years.

References:

“The 2002 Pennsylvania Statewide Inventory, Using MOBILE6, An Explanation of Methodology,” Michael Baker, Jr., Inc., November 2003.

Method 2b: Use of Traffic Data for Each Vehicle Class

Data Sources and Procedures This approach involves using county traffic count data by vehicle class. This requires data collection on a representative set of facilities over the small urban or rural area under question. The data collection requires measuring as many of the 28 MOBILE6 vehicle classes as possible. At a minimum the counts should be able to separate out LDGV, LDGT, and HDDV. If the pollutants of concern are ozone precursors then the data should reflect the July 1st date. For CO, the January 1st date should be used.

Also, an assessment should be made as to the projected trends in sales growth and scrappage to determine if the default trends used in MOBILE6 are appropriate when using this county traffic data for baseline fleet composition. The extent to which the growth and scrappage trends diverge from the baseline is an important factor that will affect estimates of future year emission estimates.

- Advantages**
- Uses county traffic count data, which are more representative of the local area than the national default.
 - Requires minimal additional resources, particularly if traffic count data by vehicle class are readily available from the State DOT.

- Limitations**
- The county traffic count data by vehicle type require a moderate level of increased resources to complete.
 - It may be difficult to gather more than a handful of vehicle classification data from the county traffic count data.
 - The traffic count data should reflected the climate season of concern; fleet mix may change significantly in some locations.

- The approach does not include local adjustments for changes in local scrappage or sales rates. Localized shifts in these trends may have substantial impact on emissions.

Example Location This methodology was used in Bannock County, Idaho to verify the percentage of LDGT1 and LDGT2 trucks had been properly developed for their region. The results showed that the national defaults were very similar to the local fleet fractions for LDGT1 and LDGT2 vehicles.

References:

Bannock Planning Organization, “FY2004 Draft Transportation Improvement Program Conformity Determination,” August 15, 2003.

Method 2c: Use of a Combination of Traffic Data and Vehicle Registration Data

Data Sources and Procedures This approach involves using traffic count data by vehicle class in combination with vehicle registration data. This requires data collection on a representative set of facilities over the small urban or rural area under question and ideally the local vehicle registration. The traffic data collection count requires collecting information on vehicle type by roadway functional class. The vehicle registration data are then used to determine the type of fuel use by vehicle type. The vehicle registration data are typically available at the county level, but may be possible to acquire at city or smaller scale from the state motor vehicle registration office. The product of the registration data and traffic count are used to determine the MOBILE6 fleet mix over the small urban or rural area under question. If the pollutants of concern are ozone precursors then the data should reflect the July 1st date. For CO, the January 1st date should be used.

Also, an assessment should be made as to the projected trends in sales growth and scrappage to determine if the default trends used in MOBILE6 are appropriate when using this baseline fleet composition. The extent to which the growth and scrappage trends diverge from the baseline is an important factor that will affect estimates of future year emission estimates.

- Advantages**
- Uses traffic count data, which are likely more representative of the local area than the national default.
 - Uses local registration data, which is likely more representative of the local area than the national default.
 - Offers an approach to develop an estimate for the full 28 MOBILE6 vehicle classification categories.
 - Appealing in estimating fleet mix in the near future as the alternative fueled and new technology (hybrid vehicles – gasoline/electric and diesel/electric) begin to enter the fleet.

- Limitations**
- The traffic count data by functional class require a moderate level of increased resources to complete.
 - The need to acquire the vehicle registration data and compute the product with the traffic count data entails a modest amount of additional resources.
 - The traffic count data should reflect the climate season of concern; fleet mix may change significantly in some locations.
 - The approach does not include local adjustments for changes in local scrappage

or sales rates. Localized shifts in these trends may have substantial impact on emissions.

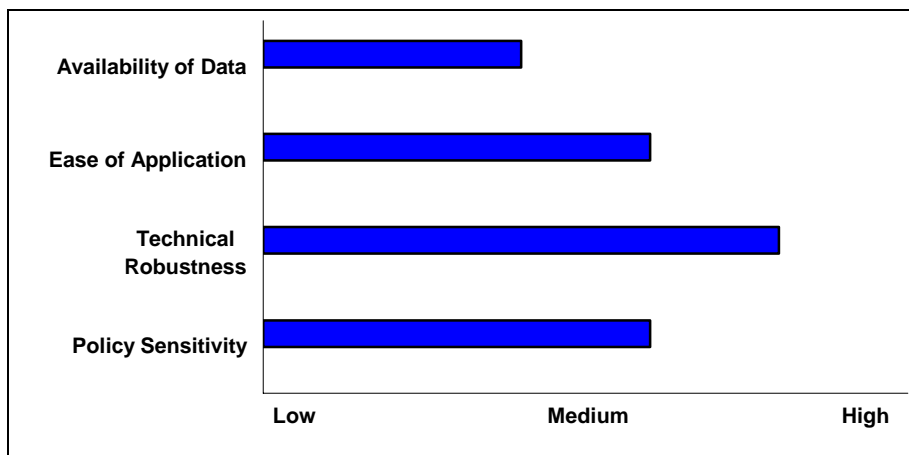
Example Location This methodology was used in Cheshire County, New Hampshire. VMT mix was estimated by using a combination of vehicle registration data and traffic count data were collected by roadway function class. County registration data was used to estimate fuel use (gasoline, diesel) by vehicle type and the cross product used to estimate the sixteen MOBILE6 vehicle mix categories. Development of a local fleet mix was identified as an important factor in helping the region meet conformity.

References:

New Hampshire Department of Transportation, "Procedure to Determine VMT Percentages by Vehicle Type in New Hampshire", August 2, 2002.

ESTIMATING VMT MIX BY VEHICLE TYPE

Method 3: Use Available Local Data for Base Year Fleet Mix and Iteratively Adjust To Reflect Expected Changes in Mix



Description The MOBILE model requires estimates of a distribution of registered vehicles by age and vehicle category for current and future years. In this case, local registration and/or local traffic data are used to characterize the vehicle mix for the 16 composite MOBILE6 vehicle classes (or potentially the full 28 MOBILE6 categories). The estimates are then iteratively adjusted for each analysis year in proportion to changes assumed in the MOBILE default values.

Method Applicability This approach is most applicable in areas where important differences are known relative to the national average vehicle fleet mix used in MOBILE6. It is applicable where the local traffic data in conjunction with vehicle type from the HPMS reporting system can be assembled and is representative of the nonattainment or maintenance area under study. Ideally, traffic survey count information classified by vehicle type at the local level can be used to estimate on-road vehicle fleet mix for the MOBILE6 model. Caution is advised in mapping the HPMS vehicle type information to the MOBILE6 model as the two classification schemes are distinctly different.

Data Sources and Procedures This approach involves using local traffic count data by vehicle class. This requires data collection on a representative set of facilities over the small urban or rural area under question. The data collection requires using historical HPMS data for the six or more vehicle classification counts and then translating to the 16 MOBILE6 composite vehicle classes. These vehicle classification counts from HPMS are used in conjunction with the default MOBILE6 vehicle mix by iteratively adjusting the distributions so that the final fleet mix reflect the change in vehicle mix for each year. At a minimum the vehicle classification counts should be able to separate out LDGV, LDGT and HDDV. If the pollutants of concern are ozone precursors then the data should reflect the July 1st date. For CO, the January 1st date should be used.

Also, an assessment should be made as to the projected trends in sales growth and scrappage trends to determine if the default trends used in MOBILE6 for future years are appropriate when using this local traffic data for baseline fleet

composition.

- Advantages**
- Uses traffic data classification counts, which are likely more representative of the area than the national default.
 - Uses only a modest additional resource requirement by using historical HPMS data; particularly if representative traffic data vehicle classification counts are readily available from the State DOT.

- Limitations**
- The traffic count data by vehicle type require a moderate level of additional resources to complete.
 - It may be difficult to gather more than a handful of vehicle classification data from the HPMS traffic classification count data.
 - The traffic count data should reflect the climate season of concern; fleet mix may change significantly in some locations.
 - The approach does not include local adjustments for changes in local scrappage or sales rates projected for future years. Localized shifts in these trends may have substantial impact on emissions.

Example Location This methodology was used across North Carolina for six urban and six rural road types. It was used primarily for adjusting the vehicle classification mix to reflect the change in fleet mix for higher light-duty truck fraction than the national average using recent historical HPMS data.

Reference:

Phone conversation with Behshad Norowzi, North Carolina DOT, bnorowzi@dot.state.nc.us), February 17, 2004.

4.3 VEHICLE AGE DISTRIBUTION

The vehicle age distribution determines the fraction of vehicles operating within each emissions control requirement standard and the deterioration of the emission control technology. Emission rates vary widely between new and older vehicles. Thus, even small changes in fleet age, particularly for older vehicles, may result in large changes in emission totals.

The MOBILE6 model requires estimates of a distribution of registered vehicles by age and vehicle category for current and future years. MOBILE6 default values were developed using national level vehicle registration data by age and class for July 1, 1996. EPA developed a methodology to convert the July 1, 1996 registration profile into a general registration distribution by age and by vehicle category for some 6 composite (gasoline and diesel) vehicle types plus motorcycles (see Table below). To project future changes, EPA evaluated general sales growth and vehicle scrappage trends for the total light-duty vehicle in-use fleet and the total heavy-duty vehicle in-use fleet, and made minor adjustments, where possible, to reflect some of the differences between vehicle categories.

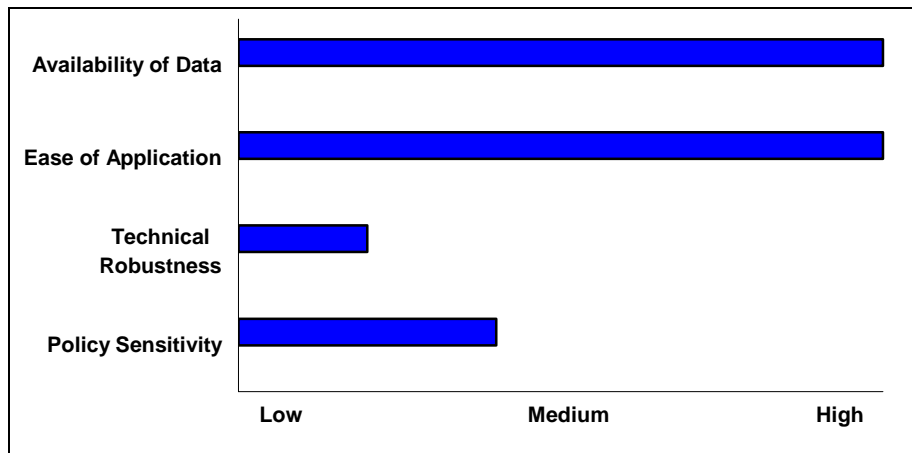
MOBILE6 U.S. Vehicle Fleet Distribution of Registration Fractions by age as of July 1

Vehicle age	LDV ALL	LDT 0 -6,000	LDT 6,001-8,500	HDV 2B-3 8,501-14,000	HDV 4-8B 14,001+	HD School Bus (All)	HD Transit. Bus (All)	MC
1*	0.0530	0.0581	0.0594	0.0503	0.0364	0.0368	0.0307	0.1440
2	0.0706	0.0774	0.0738	0.0916	0.0728	0.0736	0.0614	0.1680
3	0.0706	0.0769	0.0688	0.0833	0.0681	0.0688	0.0614	0.1350
4	0.0705	0.0760	0.0640	0.0758	0.0637	0.0642	0.0614	0.1090
5	0.0703	0.0745	0.0597	0.0690	0.0596	0.0600	0.0614	0.0880
6	0.0698	0.0723	0.0556	0.0627	0.0557	0.0561	0.0614	0.0700
7	0.0689	0.0693	0.0518	0.0571	0.0521	0.0524	0.0614	0.0560
8	0.0676	0.0656	0.0482	0.0519	0.0487	0.0489	0.0614	0.0450
9	0.0655	0.0610	0.0449	0.0472	0.0456	0.0457	0.0614	0.0360
10	0.0627	0.0557	0.0419	0.0430	0.0426	0.0427	0.0613	0.0290
11	0.0588	0.0498	0.0390	0.0391	0.0399	0.0399	0.0611	0.0230
12	0.0539	0.0436	0.0363	0.0356	0.0373	0.0373	0.0607	0.0970
13	0.0458	0.0372	0.0338	0.0324	0.0349	0.0348	0.0595	0.0000
14	0.0363	0.0309	0.0315	0.0294	0.0326	0.0325	0.0568	0.0000
15	0.0288	0.0249	0.0294	0.0268	0.0305	0.0304	0.0511	0.0000
16	0.0228	0.0195	0.0274	0.0244	0.0285	0.0284	0.0406	0.0000
17	0.0181	0.0147	0.0255	0.0222	0.0267	0.0265	0.0254	0.0000
18	0.0144	0.0107	0.0237	0.0202	0.0250	0.0248	0.0121	0.0000
19	0.0114	0.0085	0.0221	0.0184	0.0234	0.0231	0.0099	0.0000
20	0.0090	0.0081	0.0206	0.0167	0.0219	0.0216	0.0081	0.0000
21	0.0072	0.0078	0.0192	0.0152	0.0204	0.0202	0.0066	0.0000
22	0.0057	0.0075	0.0179	0.0138	0.0191	0.0189	0.0054	0.0000
23	0.0045	0.0072	0.0167	0.0126	0.0179	0.0176	0.0044	0.0000
24	0.0036	0.0069	0.0155	0.0114	0.0167	0.0165	0.0037	0.0000
25	0.0103	0.0360	0.0732	0.0499	0.0799	0.0783	0.0115	0.0000

Note: age 1 = 75% of age 1 as predicted by the curve fit analysis to reflect a July 1 population of age 1 vehicle.

ESTIMATING VEHICLE AGE DISTRIBUTION

Method 1: Use MOBILE6 Model Defaults



Description The MOBILE model requires estimates of a distribution of registered vehicles by age and vehicle category for current and future years. This approach uses the national default registration distribution in MOBILE6.

Method Applicability This method is most applicable in a nonattainment or maintenance area where it is believed that the vehicle fleet age is similar to the national default. This is most likely the case in areas that parallel national socioeconomic statistics. This assessment should include all on-road vehicles in the area including those outside the nonattainment or maintenance area if a considerable portion of vehicles in the on-road fleet come from outside the area.

Data Sources and Procedures This approach involves using the national default registration distribution that comes with the MOBILE6 model. A review of the national registration data should be made in order to verify the appropriateness of the national default data. This review could look at the most important classes of vehicles: light-duty gas vehicles and heavy-duty diesel vehicles.

Also, an assessment should be made as to the projected trends in sales growth and scrappage trends to determine if the default trends used in MOBILE6 are appropriate. The extent to which the growth and scrappage trends diverge from the national default in the future is an important factor that will affect estimates of future emissions.

- Advantages**
- Uses a readily available, nationally recognized source of data that requires little effort for the user to apply.
 - Use of the national average facilities comparisons to other regions using the national averages for the vehicle age distribution.

- Limitations**
- Area may have a VMT age distribution that varies significantly from the national default. Thus, the approach may not provide a valid representation of the actual fleet age distribution.
 - Sensitivity tests conducted by EPA¹⁵ found that only a 20% age shift to older vehicles can increase emissions for hydrocarbons and CO by as much as 50% depending on the calendar year of evaluation and up to 40% for NO_x.
 - Approach does not include local adjustments for changes in local scrappage or sales rates. Localized shifts in these trends may have substantial impact on emissions.
 - Use of national defaults may have important implications on policy decisions if vehicle registration fees are tied to age of vehicle (i.e., as done in many counties to help reduce emissions a policy could be made to increase license fees as the vehicle ages to encourage people to use newer low-emitting vehicles)

Example Location This methodology has been applied in Portneuf Valley, Bannock County, Idaho. However, efforts were underway to obtain a VIN decoder that would enable them to use a county specific fleet age distribution because of concerns about using the national default values for this small urban area of Pocatello and Chubbuck.

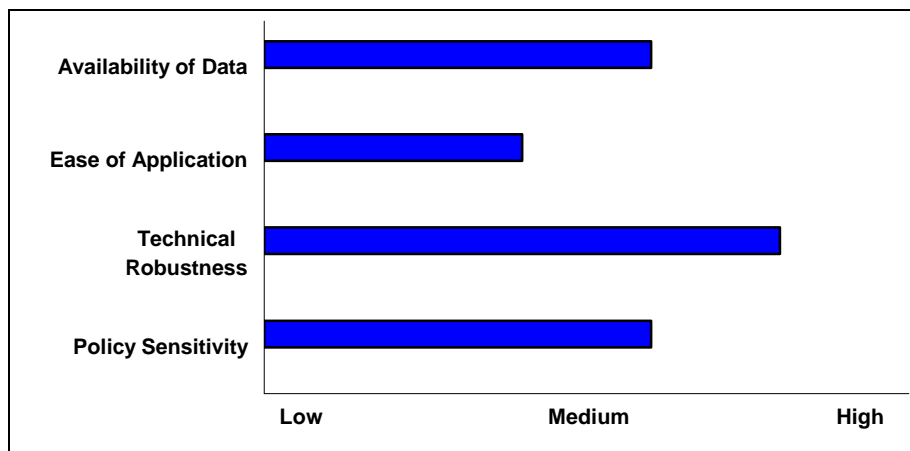
References:

Bannock Planning Organization, "FY2004 Draft Transportation Improvement Program Conformity Determination," August 15, 2003.

¹⁵ USEPA, 2002. "Sensitivity Analysis of MOBILE6.0", Assessment and Standards Division, Office of Transportation and Air Quality, EPA420-R-02-035, December 2002.

ESTIMATING VEHICLE AGE DISTRIBUTION

Method 2: Use Local Vehicle Registration Data for In-Use Fleet



Description The MOBILE model requires estimates of a distribution of registered vehicles by age and vehicle category for current and future years. This approach uses local vehicle registration data to develop these inputs.

Method Applicability This approach is most applicable in areas where there are significant differences in the local vehicle fleet age distribution relative to the national average. It is most applicable where the local registration data can be assembled and are representative of the nonattainment or maintenance area. Ideally, registration data at the local level can be used to estimate vehicle age distribution. However, adjustments may be needed if a significant portion of on-road motor vehicles is from outside the nonattainment area.

Data Sources and Procedures This approach involves using local vehicle registration data. This is typically available at the county level, but may also be applied using statewide data from the state motor vehicle registration office. The fleet age should be representative of the vehicle fleet over the small urban or rural area under question. If the pollutants of concern are ozone precursors, then the data should reflect the July 1st date. For CO, the January 1st date should be used.

Also, an assessment should be made as to the projected trends in sales growth and scrappage trends to determine if the default trends used in MOBILE6 are appropriate when using this local vehicle registration data for baseline age distribution. The extent to which the growth and scrappage trends diverge from the baseline is an important factor that will affect estimates of future year emission estimates.

- Advantages**
- Uses locally specific registration data, which is likely more representative of the local area than the national default.
 - Requires minimal additional resources, particularly if data is readily available at the county or local level from the State department of motor vehicle registration.
 - Recommended by EPA and generally is encouraged as a preferred approach over the national default approach.

- Limitations**
- May include vehicles owned, but not operated in the local area.
 - Registration data does not differentiate between seasonal usage differences in vehicles. For example, in some locations LDGT are operated more frequently in the winter months with the need for better traction in winter driving conditions. Conversely, more LDGV are used in summer months when driving conditions are less demanding.
 - Does not include local adjustments for changes in local scrappage or sales rates. Localized shifts in these trends may have substantial impact on emissions.

Example Location The basic methodology has been applied in several locations, including Cheshire County, NH and in Missoula County, MT.

In Berks County in Pennsylvania, the Pennsylvania Department of Transportation used the same approach, except for heavy-duty vehicles, where the distribution was estimated using the internal MOBILE6 age distributions, since much of Pennsylvania's heavy-duty vehicle traffic is through traffic and therefore not registered in the state.

The Bay Lake Regional Planning Commission in Wisconsin used the same approaches but distributions were only made at the highest level for the three major vehicle classes of LDGT, LDGT and HDDV. Also, data were only applied using state registration distributions.

For small urban and rural areas in North Carolina, the North Carolina Department of Transportation developed age distributions based on registration data for the eight vehicle types for those portions of the state outside the state's three major urban areas.

References:

Bay-Lake Regional Planning Commission, "Assessment of Conformity of the Year 2025 Sheboygan Area Transportation Plan and the 2004-2007 Sheboygan Metropolitan Planning Area Transportation Improvement Program with Respect to the State of Wisconsin Air Quality Implementation Plan," 2003.

New Hampshire Department of Transportation, "Procedure to Determine VMT Percentages by Vehicle Type in New Hampshire", August 2, 2002.

Montana Department of Environmental Quality, Vehicle Fractions by Functional Roadway Classifications, February 25, 2004.

Pennsylvania Department of Environmental Protection, "The 2002 Pennsylvania Statewide Inventory Using MOBILE6, An Explanation of Methodology," Prepared by Michael Baker, Jr., Inc. November 2003.

4.4 PERCENT OF VMT ON FREEWAY RAMPS

In the MOBILE6 model, there are four sets of driving cycles that are modeled separately, representing different types of functional classes of roadways:

- Freeway (excluding ramps)
- Arterial/collector
- Local roadway
- Freeway ramp

The fraction of vehicle miles traveled (VMT) by highway functional system (also called “roadway type” or “facility type”) varies from area to area and can have a significant effect on overall emissions from highway sources. For SIP-related highway vehicle emission inventory development in moderate and above non-attainment areas, EPA expects states to develop and use their own specific estimates of VMT by highway functional system. Each driving cycle may be run separately, with analysis results combined outside of the MOBILE6 model, or the user may use the ability of MOBILE6 to combine the results into a single composite emission rate.

It is important for transportation agencies to understand what the MOBILE roadway classifications represent since each driving cycle set implies different assumptions about vehicle activity and different emission estimates in MOBILE6. These classifications may not always match with definitions used by transportation agencies. In particular, most transportation agencies do not explicitly account for freeway ramp VMT separately. Since freeway ramp activity is not included in MOBILE6 in the freeway driving cycle set, freeway VMT must include a corresponding amount of freeway ramp VMT in MOBILE6 to account for acceleration and deceleration to and from freeway speeds. MOBILE6 models freeway ramp VMT based on the assumption that freeway ramps are 8% of all VMT assigned to both freeways and freeway ramps. MOBILE6 models all freeway ramps at a fixed average speed of 34.6 miles per hour. If the freeway ramp VMT is accounted for in other driving cycle sets (i.e., collector roadways), then the VMT in those roadways must be reduced by the amount of VMT assigned to the freeway and freeway ramp combination.

If the user does not choose to provide these percentages, MOBILE6 uses the following default values.

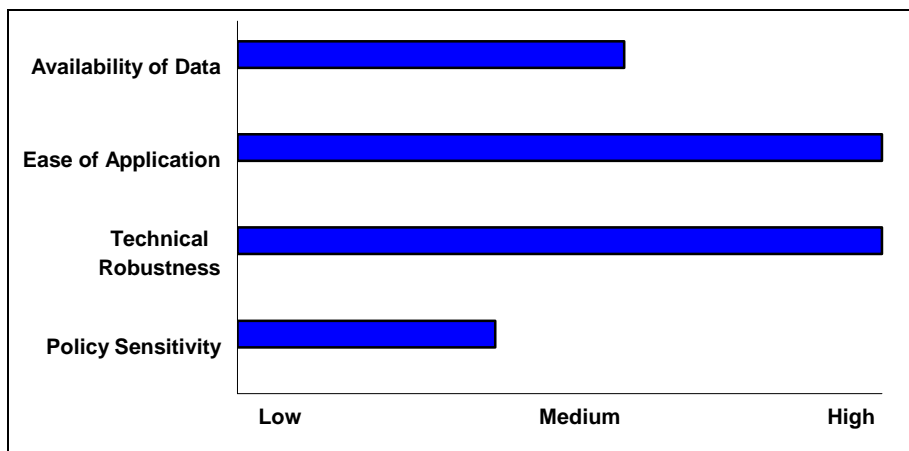
- Freeway (excluding ramps) – 34%
- Arterial/collector – 50%
- Local roadway – 13%
- Freeway ramp – 3%

While areas should use local data to estimate the VMT on each classification, given that most areas do not collect specific estimates of VMT on freeway ramps, a default percentage of 8 percent of freeway VMT on ramps (3 percent/34 percent) is generally recommended for use by EPA. This percentage, however, is a national average, and rural areas may have a lower percentage of VMT on freeway ramps due to the limited number of interchanges and large distances between interchanges in comparison to more urban areas. As a result, it may be useful

for an area to consider a local study to estimate the freeway ramp percentage. This approach is described below.

ADDRESSING PERCENT VMT ON FREEWAY RAMPS

Method: Use Local Data on Percent of Freeway Traffic on Ramps



Description This methodology involves collecting data on route mileage of ramps and vehicle travel on ramps from local traffic counts in order to develop a better estimate of the percent of freeway VMT on ramps.

Method Applicability This method is most applicable in an area where there is reason to believe that the percent of freeway VMT on ramps is significantly different from the MOBILE6 default. This is most likely to be the case in rural areas with few interchanges.

Data Sources and Procedures This approach involves collecting data on ramp traffic from a ramp count survey and collecting detailed data on the route mileage of ramps compared to the highway itself. This estimated percentage of the area’s interstate/freeway VMT that occurs on freeway ramps is then used to estimate total VMT on freeway ramps. An emissions factor for the freeway ramps is then developed and applied to the VMT to estimate emissions on freeway ramps.

- Advantages**
- Simplicity of the approach.
 - Uses local data to better characterize travel activity.
 - Requires limited amount of new data collection.

Limitations

- Requires collection of additional data.

Example Location This methodology has been applied in rural areas of Kentucky. The Kentucky Transportation Cabinet (KYTC) conducted a rural ramp count survey over a 3-week period, and found that ramp VMT was roughly 1.5 percent of interstate VMT in rural areas. This estimate was significantly below the level assumed in the MOBILE6 default, and had implications on the emissions results since MOBILE6 assumes that average ramp speed is 34.6 miles per hour, which is significantly lower than the average speed on rural highways.

Reference: Phone conversation with Jesse Mayes and Barry House, Kentucky Transportation Cabinet, Jesse.Mayes@ky.gov, February 20, 2004.

4.5 I/M PARTICIPATION

Many areas have implemented inspection and maintenance (I/M) programs to reduce mobile source emissions. Many of the choices for these I/M program specifications are at the discretion of the local agency depending upon the severity of the air pollution problem and the air pollutant of concern. The types of vehicles in the program as well as the types of I/M program may have significant impacts on the estimated emission rates. For example, areas that have employed the most stringent level of I/M program (IM240) have found on-road emission reductions for CO of 45%, hydrocarbon (HC) as large as 35%, and up to 12% for NO_x relative to conditions without the I/M program.¹⁶ For the more minimal I/M programs (biennial emission idle test), reduction benefits are estimated at 19% for CO, 17% for HC, and 0.5% for NO_x. Thus, the choice of program may have potentially significant changes in emission totals.

MOBILE6 is capable of modeling the impact of up to seven different exhaust and evaporative emission I/M programs on emission factors. By defining multiple I/M emission reduction programs, the user can model different requirements on different types and ages of vehicles or different requirements in different calendar years. MOBILE6 also allows users to enter a number of I/M program parameters to better model specific I/M program features. These parameters include:

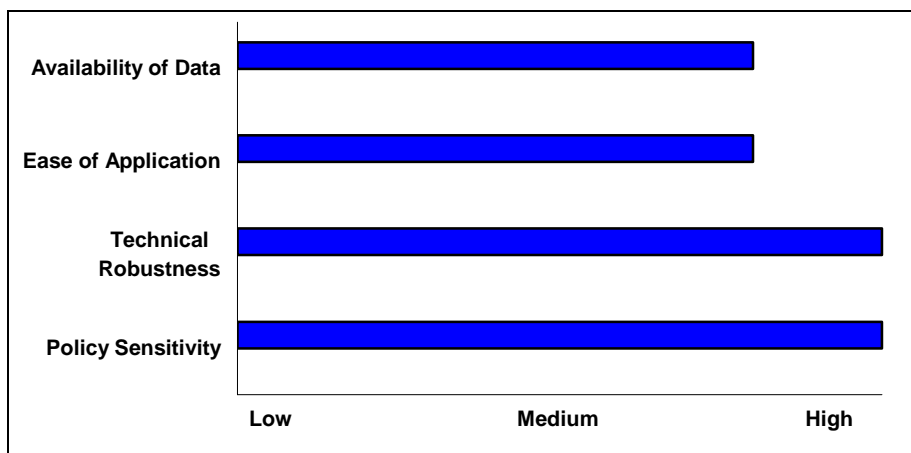
- Ability to model annual or biennial I/M programs.
- Ability to model Idle, 2500/Idle, acceleration simulation model (ASM), IM240 (an emission test which measures emissions as the vehicle is driven on a dynamometer through a driving cycle taking up to 240 seconds that simulates actual urban driving), and onboard diagnostic (OBD) exhaust I/M programs.
- Ability to model gas cap, fill-pipe pressure test, and OBD check evaporative I/M programs.
- Ability to control model year coverage.
- Ability to control vehicle class coverage (only gasoline-fueled vehicles can be modeled for I/M).
- Ability to vary the failure rate of the exhaust I/M program for pre-1981 model year vehicles.
- Ability to vary the compliance rate of the I/M program.
- Ability to vary the waiver rate of the I/M program.
- Ability to vary the “cutpoints” (which determine whether a vehicle passes or fails an I/M test) by pollutant, vehicle type, and age used in an IM240 program.
- Ability to account for the effect of exempting old vehicles from program requirements.
- Ability to account for the effect of exempting new vehicles from program requirements
- Ability to eliminate the effects of technician training on exhaust I/M performance.

In addition, the mere presence of an I/M program is expected to act as a deterrent to tampering. Thus, in areas with an I/M program, MOBILE6 will reduce the tampering rates even if there is no anti-tampering program. All 1996 and newer model year vehicles are assumed to have negligible tampering effects in MOBILE6. As a result, there is no tampering reduction benefit associated with the 1996 and newer vehicles.

¹⁶ *Evaluating Vehicle Emissions Inspection and Maintenance Programs*, Committee on Vehicle Emission Inspection and Maintenance Programs, Transportation Research Board, National Research Council, National Academy of Press, 2001. ISBN 0-309-07446-0.

ADDRESSING I/M PARTICIPATION

Method 1: Apply Type of I/M Program to Area of Analysis



Description This methodology uses the local I/M program requirements to define the on-road vehicle fleet that is participating in I/M programs. The approach allows the user to define the local I/M program through the application of the MOBILE6 model. For regions that have significant numbers of vehicles subject to other I/M programs, the MOBILE6 model will need to be applied separately for each I/M program.

Method Applicability This method is most applicable in a nonattainment or maintenance area where the I/M participation rate in the on-road vehicle fleet is essentially the same as the percentage of vehicles registered in the jurisdiction subject to I/M. In regions where a significant portion of the on-road fleet is from outside the local I/M area, an estimate must be made for the fraction of those vehicles outside the local region (see Method #2).

Data Sources and Procedures This approach involves running the local specific I/M program requirements through the MOBILE6 model to estimate the effects of the I/M program. If, through the use of local survey data, a significant fraction of the on-road fleet is found to be registered outside the jurisdiction of the local I/M program then the procedure should be modified, as described in Method #2.

In order to forecast emissions, the analysis can account for a change in the counties or local areas where I/M programs will be required in the future. The extent to which I/M program requirements change in the future is an important factor that will affect estimates of future emissions.

- Advantages**
- Uses the local specific I/M program requirements as defined in local regulations.
 - Approach is straightforward and would generally be considered an acceptable approach providing it can be demonstrated that the approach is representative.
 - Relatively simple to apply and can be modified easily to account for non-I/M effects through the use of survey data.

- Limitations**
- The local I/M participation rate may be an invalid representation of the on-road fleet. For example, a number of vehicles from outside the region may pass through the local area, particularly in donut shaped areas, and may therefore cause the local I/M participation rate not to be representative of the local on-road emission rate.
 - If survey data is used to estimate the on-road fleet fraction outside the local I/M program control, it may not be representative if an inadequate number of survey days are sampled.

Example Location This methodology has been applied in both Pennsylvania's Berks County and Wisconsin's Bay Lake Regional Planning Commission.

In Berks County the I/M program began in 2003 for LDGV and LDGT vehicles only. 1996 and newer vehicles had their OBD computer checked, for 1975 to 1995 model year cars an anti-tampering program with seven inspections is performed and for all years a gas cap pressure check is done.

For Wisconsin, emission factors included different model year vapor recovery programs and more basic inspection maintenance procedures. Five vehicle classes were subject to the program: LDGV, LDGT (1 thru 4), and HDGV2B.

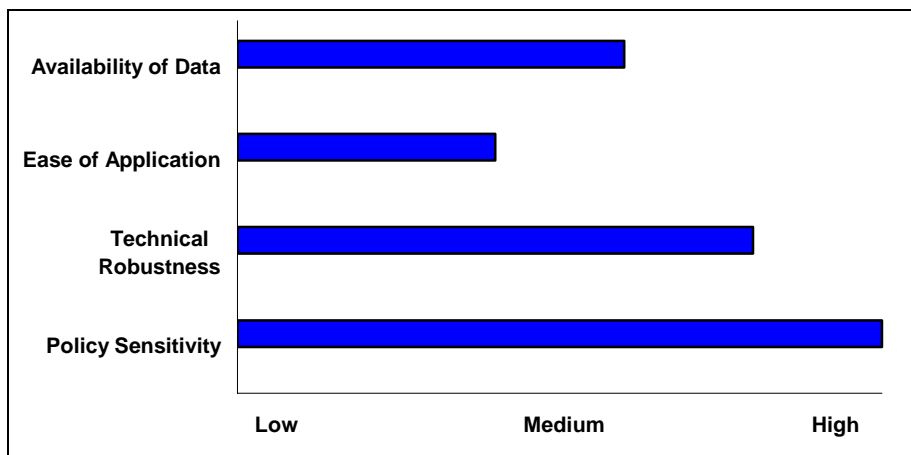
References:

Bay-Lake Regional Planning Commission, Wisconsin DOT, and Wisconsin Department of Natural Resources, *Assessment of conformity of the Year 2025 Sheboygan Area Transportation and the 2004-2007 Sheboygan Metropolitan Planning Area Transportation Improvement Program (TIP) with Respect to the State of Wisconsin Air Quality Implementation Plan*, Fall 2003.

Michael Baker, Jr., Inc., "The 2002 Pennsylvania Statewide Inventory, Using MOBILE6, An Explanation of Methodology," November 2003.

ADDRESSING I/M PARTICIPATION

Method 2: Use Accident or Other Data Sources to Estimate Proportion of Traffic Subject to I/M



Description This methodology uses vehicle accident data, or other vehicle data, to estimate the proportion of vehicles in the on-road vehicle fleet that are participating in Inspection & Maintenance (I/M) programs. The approach is unique in that it accounts for the fact that some vehicles traveling in a jurisdiction are registered in another jurisdiction that may not be subject to the same requirements.

Method Applicability This method is most applicable in a nonattainment or maintenance area where there is reason to believe that the I/M participation rate in the on-road vehicle fleet is significantly different than the percentage of vehicles registered in the jurisdiction subject to I/M (for example, if a jurisdiction does not have an I/M program but a considerable portion of vehicles in the on-road fleet come from other jurisdictions that do, or alternatively, if the jurisdiction has an I/M program and considerable traffic comes from other jurisdictions that do not). This would be particularly important where an I/M program is not statewide and if there is a high level of inter-county or interstate travel.

Data Sources and Procedures This approach involves using accident data in order to estimate the proportion of vehicles in the on-road fleet that are from jurisdictions subject to I/M program requirements. Accident data are used to determine the county in which vehicles on the road are registered. Based on place of registration, the proportion of vehicles on the road that are subject to I/M programs can be determined.

The MOBILE model is run twice—once with an I/M program and once without an I/M program. A weighted emissions factor is then calculated by multiplying the MOBILE emissions factor with I/M by the percent of vehicles from jurisdictions subject to I/M, plus the MOBILE emissions factor without I/M by the percent of vehicles from jurisdictions without I/M requirements.

To forecast emissions, the analysis can account for a change in the counties where I/M programs will be required in the future. The extent to which I/M program requirements change in the future is an important factor that will affect estimates of future emissions.

- Advantages**
- Uses a readily available source of data on a county-by-county level. Virtually all counties collect accident data due to its obvious uses related to improving safety in high accident areas.
 - Use of the data to estimate the proportion of vehicles subject to I/M is an innovative approach to using existing data for new purposes.
 - Relatively simple to operationalize and improves the quality of data used in analysis (i.e., national defaults or local inputs).

- Limitations**
- Accident data may not provide a valid representation of the proportion of in area vs. out-of-area vehicles.
 - The quality of the accident data may create biases. For example, if many accidents occur at nighttime, the mix of vehicles on the road could be very different than during an average day.

Example Location This methodology has been applied in North Carolina. This methodology was selected since an I/M program currently is limited to nine counties and there is significant county-to-county commuting. The NCDOT assumes that the I/M program in the State will be in force in 48 counties in 2007.

This methodology was used across North Carolina for six urban and six rural road types. It was used primarily for adjusting the vehicle classification mix to reflect the change in fleet mix for higher light-duty truck fraction than the national average using recent historical HPMS data.

References:

Phone conversation with Behshad Norowzi, North Carolina DOT, bnorowzi@dot.state.nc.us), February 17, 2004.

5 SUMMARY

Small urban and rural areas that are required to conduct conformity analysis typically face many challenges in conducting the regional emissions analysis: limited data on VMT and speeds, lack of a travel demand forecasting (TDF) model, and often limited staff expertise in emissions modeling. While large metropolitan areas generally have advantages in terms of resources, data, and tools, it is important to recognize that valid methods are available to conduct the regional emissions analysis in small urban and rural areas.

This document provides a sampling of methodologies and adjustment techniques for developing estimates of VMT and speeds, the two key inputs required for emissions modeling. It also describes other factors that influence emissions factors, and highlights approaches for using local data rather than MOBILE6 model defaults. Each option has certain advantages and limitations. There is no “one-size fits all” approach that should be applied in all areas. Areas subject to conformity should identify what methods are most appropriate to their region through the interagency consultation process. The selected methods should reflect data availability and local conditions. Other options beyond those profiled in this report may also be available, and regions should explore other possibilities.

6 RESOURCES

Resources on Regional Emissions Analysis Methodologies

2000 Highway Capacity Manual, Transportation Research Board, Washington D.C., 2000.

Analysis of Traffic Growth Rates, M.L. Barrett, R.C. Graves, D.L. Allen, J.G. Pigman, G. Abu-Lebdeh, L. Aultman-Hall, S.T. Bowling, University of Kentucky Transportation Center, August 2001.

Development of On-Road Mobile Source Emission Inventories for Rural Counties, G. B. Dresser, D. G. Perkinson, Texas Transportation Institute, May 2001.

<http://www.epa.gov/ttn/chief/conference/ei10/index.html#ses-6>

HERS-ST v20: Highway Economic Requirements System - State Version Technical Report, FHWA, November 17, 2003. Online at: <http://isddc.dot.gov/OLPFiles/FHWA/010945.pdf>.

Highway Speed Estimation for MOBILE6, Bob Bostrom and Jesse Mayes, Kentucky Transportation Cabinet, 2002.

Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications, NCHRP Report 387, Transportation Research Board, Dowling, R.; Kittelson, W; Zegeer, J.; Skabardonis, A, 1997.

Rural Conformity: A Survey of Practice, NCHRP, Project 08-36, Task 28, ICF Consulting and Sarah J. Siwek & Associates, October 2003.

Vehicle Miles of Travel Projections and Speed Estimates for Rural Nonattainment and Maintenance Areas, John Gardner, South Carolina Department of Transportation, presented at Southern Transportation and Air Quality Summit, October 2001, Atlanta, Ga.

General Resources on Conformity Requirements, Guidance, and Training

Conformity Requirements: Title 40 of the Code of Federal Regulations (40 CFR Parts 51 and 93) http://www.access.gpo.gov/nara/cfr/waisidx_99/40cfr93_99.html

Transportation Conformity: A Basic Guide for State and Local Officials, U.S. Federal Highway Administration, Revised June 19, 2000.

http://www.fhwa.dot.gov/environment/conformity/con_bas.htm

Transportation Conformity Reference Guide. Federal Highway Administration (last updated July, 2001) http://www.fhwa.dot.gov/environment/conformity/ref_guid/index.htm

Clean Air Act (42 USC 7401-7671q) <http://www.epa.gov/oar/caa/contents.html>

SIP Requirements <http://www.epa.gov/oar/caa/contents.html>

National Transit Institute (NTI) Course on Introduction to Transportation/Air Quality
Conformity: <http://www.ntionline.com>

National Highway Institute (NHI) Course on Estimating Regional Mobile Source Emissions
<http://www.nhi.fhwa.dot.gov>

Other FHWA/EPA Conformity Resources, including Transportation Conformity Community of
Practice: <http://www.fhwa.dot.gov/environment/conform.htm>

Appendix

Parameters and Defaults Values for Use with the BPR Formula for Estimating Speed

As described in Section 3, use of the BPR-type formulas (and other methods) requires three inputs: free-flow speed, roadway capacity, and traffic volume. Traffic volume information is developed as described in Section 2 of this report. The accuracy of this method is highly dependent on the accuracy of the capacity and free-flow speed inputs. This appendix described in detail the procedures for developing these two inputs, including default parameter values and some examples.

Free-flow speed estimation

NCHRP Report 387 recommends estimating free-flow speed by link using separate equations for unsignalized and signalized facilities.

Free-flow speed equation for unsignalized facilities:

$$\begin{aligned} \text{Free-flow speed} &= 0.88 * S_p + 14 \text{ (High-speed facilities have posted speed} > 50 \text{ mph)} \\ \text{Free-flow speed} &= 0.79 * S_p + 12 \text{ (Low-speed facilities have posted speed} \leq 50 \text{ mph)} \end{aligned}$$

where S_p = posted speed limit in mph

Free-flow speed equation for signalized facilities:

$$\text{Free-flow speed} = \frac{L}{L/S_{mb} + N * (D/3600)}$$

where: L = length of facility (in miles)

S_{mb} = mid-block free-flow speed = $0.79 * \text{posted speed} + 12$ mph

N = number of signalized intersections on length, L

D = average delay per signal

$$D = DF * 0.5 * C(1-g/C)^2$$

where: D = total signal delay per vehicle (sec)

g = effective green time (sec)

C = cycle length (sec)

If signal timing data are not available, the following default values can be used:

$C = 120$ seconds

$g/C = 0.45$

$DF = (1 - P)/(1 - g/C)$, where P = proportion of vehicles arriving on green

If P is unknown, the following defaults can be used for DF :

$DF = 0.9$ for uncoordinated traffic actuated signals

= 1.0 for uncoordinated fixed time signals

= 1.2 for coordinated signals with unfavorable progression

= 0.90 for coordinated signals with favorable progression

= 0.60 for coordinated signals with highly favorable progression

When using these equations to estimate free-flow speed on a large number of links, it is typically impractical to apply the equations individually for each link. Instead, the equations are used to develop look-up tables of free-flow speeds by facility type and area type. The look-up table is then used to quickly assign free-flow speeds to each link. Below is an example of such a look-up table.

Example – Look-up table of default free-flow speeds (mph)

	Free-flow speeds (mph)				
	Freeway	Expressway	Arterial	Collector	Local
CBD	50	45	40	35	30
Urban	55	50	45	40	35
Suburban	60	55	50	45	40
Rural	65	60	55	50	45

Source: *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications*, NCHRP Report 387, Transportation Research Board, 1997.

Free-flow speeds can be determined using other more simplistic methods. Some regions estimate flow speeds by facility type based on the posted speed limit, such as adding or subtracting a fixed amount to/from the speed limit (e.g., speed limit plus 5 mph for highways) or multiply the speed limit by a fixed percentage (e.g., 62% of speed limit for collectors). These simple adjustments to posted speed limits are usually based on a limited sample of measured local speeds that are available for the desired roadway classification. When using these rules for estimating free-flow speeds, the equations often differ based on area type (e.g., CBD, rural, etc.). Other regions estimate free-flow speeds by facility type using observed off-peak speeds.

Roadway capacity estimation

NCHRP Report 387 recommends a set of equations for estimating capacity that are based on the 1994 *Highway Capacity Manual*. There are separate equations for freeways, 2-lane unsignalized roads, and signalized arterials.

Capacity equation for freeways and unsignalized multilane roads:

$$Capacity (vph) = Ideal Cap * N * F_{hv} * PHF$$

Where:

Ideal Cap = 2,400 (pcphl) for freeways with ≥ 70 mph free-flow speed
= 2,300 (pcphl) for all other freeways (free-flow speed < 70 mph)

N = number of through lanes (Ignore auxiliary lanes and “exit only” lanes)

F_{hv} = heavy vehicle adjustment factor
= $100 / (100 + 0.5 * HV)$ for level terrain
= $100 / (100 + 2.0 * HV)$ for rolling terrain
= $100 / (100 + 5.0 * HV)$ for mountainous terrain

(*HV* = proportion of heavy vehicles, including trucks, buses, recreational vehicles, in the traffic flow. If *HV* is unknown, use 0.05 heavy vehicles as default.)

PHF = peak-hour factor (ratio of the peak 15-min flow rate to the average hourly flow rate) (If unknown, use default value of 0.90.)

Capacity equation for two-lane unsignalized roads:

$$\text{Capacity (vph)} = \text{Ideal Cap} * N * F_w * F_{hv} * PHF * F_{dir} * F_{nopass}$$

Where: *Ideal Cap* = 1,400 (pcphl) for all two-lane rural roads

N = number of lanes

F_w = lane width and lateral clearance factor

= 0.80 if narrow land and/or narrow shoulders are present

= 1.00 otherwise

(Narrow lanes are less than 12 ft. (3.6 m) wide; narrow shoulders are less than 3 ft (1.0 m) wide.)

F_{hv} = heavy vehicle adjustment factor

= 100/(100 + 1.0 * HV) for level terrain

= 100/(100 + 4.0 * HV) for rolling terrain

= 100/(100 + 11.0 * HV) for mountainous terrain

(HV = proportion of heavy vehicles, including trucks, buses, recreational vehicles, in the traffic flow. If HV is unknown, use 0.05 heavy vehicles as default.)

PHF = peak-hour factor (ratio of the peak 15-min flow rate to the average hourly flow rate) (If unknown, use default value of 0.90.)

F_{dir} = directional adjustment factor

= 0.71 + 0.58 * (1.00 – peak direction proportion) (Peak direction proportion of two-way traffic going in peak direction. If not known, use default of 0.55 peak direction.)

F_{nopass} = no-passing zone factor

= 0.97 – 0.07 * (NoPass) for rolling terrain

= 0.91 – 0.13 * (NoPass) for mountainous terrain

(NoPass is the proportion of length of facility for which passing is prohibited. If NoPass is unknown, use 0.60 NoPass for rolling terrain and 0.80 for mountainous terrain.)

Capacity equation for signalized arterials:

$$\text{Capacity (vph)} = \text{Ideal Sat} * N * F_{hv} * PHF * F_{park} * F_{bay} * F_{CBD} * g/C * F_c$$

Where: *Ideal Sat* = ideal saturation flow rate (vehicles per lane per hour of green)
= 1,900

N = number of through lanes (Exclude exclusive turn lanes and short lane additions.)

F_{hv} = heavy vehicle adjustment factor

= 1.00/(1.00 + HV)

(HV = proportion of heavy vehicles, including trucks, buses, recreational vehicles, in the traffic flow. If HV is unknown, use 0.05 heavy vehicles as default.)

PHF = peak-hour factor (ratio of the peak 15-min flow rate to the average hourly flow rate) (If unknown, use default value of 0.90.)

F_{park} = on-street parking adjustment factor

= 0.90 if on-street parking is present and time limit is 1 hr or less

- = 1.00 otherwise
- F_{bay} = left turn bay adjustment factor
 - = 1.10 if exclusive left turn lanes (often as left turn bay) are present
 - = 1.00 otherwise
- F_{CBD} = central business district adjustment factor
 - = 0.90 if located in CBDs
 - = 1.00 elsewhere
- g/C = ratio of effective green time per cycle
 - If no data are available, use the following defaults:
 - Protected left turn phase present: $g/C = 0.40$
 - Protected left turn phase not present: $g/C = 0.45$
 - Other defaults may be developed by the local planning agency based on local conditions. Additional defaults might be based on the functional class of major and crossing streets.
- F_c = optional user-specified calibration factor necessary to match estimated capacity with field measurements or other independent estimates of capacity (no units) (can be used to account for the capacity-reducing effects of left and right turns made from through lanes)

As with free-flow speeds, it is usually impractical to apply the capacity equations individually for every link, so look-up tables are developed.

Example – Look-up table of practical capacity for original BPR curve

	One-way LOS "C", vehicles per lane per hour				
	Freeway	Expressway	2-Way	One-Way	Two-Way
			Arterial (w/ parking)	Arterial (w/ parking)	Arterial (no parking)
CBD	1750	800	600	700	600
Fringe	1750	1000	550	550	800
Outer CBD	1750	1000	550	650	800
Rural/Residential	1750	1000	550	900	800

Source: *Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications*, NCHRP Report 387, Transportation Research Board, 1997.

If traffic volume data is on a daily basis (AADT), then hourly capacity must be converted to an effective daily capacity. In one approach to calculate 24-hour capacity, the hourly capacity per lane is divided by the ratio of AADT that occurs in the peak hour. This figure is then multiplied by the number of lanes in the peak direction, and in the off peak direction is multiplied by the number of lanes and a directional adjustment factor. A 24-hour volume-to-capacity (V/C) ratio is then calculated by dividing AADT by 24-hour capacity.

Construction of a Localized Capacity Look-Up Table

Because the accuracy of capacity estimates is essential to the accuracy of speed estimates, NCHRP Report 387 recommends that planning agencies use the specific capacities of the selected study section. When that is not possible, the following tables demonstrate the procedure for selecting default values and computing a look-up table of capacities, according to facility, area, and terrain type. The first table is for two-lane, rural undivided arterials, but additional rows of data could be added for multilane rural undivided arterials.

The second table provides a sample computation.

Example – Table for Entering Default Values for Computing Capacity by Functional Class and Area/Terrain Type

Functional Class	Area Type	Terrain Type	Lanes	Free Speed	Lane Width	PHF	% Heavy Vehicles	Direction Split	% No Pass	Parking	Left Turn Bay	g/C
Freeway	Rural	Level	all	>70 mph		0.85	5%					
		Rolling	all	>70 mph		0.85	5%					
	Mountain	all	<70 mph		0.85	5%						
	Urban	all	all	<70 mph		0.90	2%					
Divided Arterial	Rural	Level	>2	60 mph		0.85	5%					
		Rolling	>2	55 mph		0.85	5%					
		Mountain	>2	50 mph		0.85	5%					
	Suburban	all	all			0.90	2%			no	yes	0.45
	Urban	all	all			0.90	2%			yes	yes	0.45
	CBD	all	all			0.90	2%			yes	yes	0.45
Undivided Arterial	Rural	Level	2		standard	0.85	5%	55%	0%			
		Rolling	2		standard	0.85	5%	55%	60%			
		Mountain	2		narrow	0.85	5%	55%	80%			
	Suburban	all	all			0.90	2%			no	no	0.45
	Urban	all	all			0.90	2%			yes	no	0.45
	CBD	all	all			0.90	2%			yes	no	0.45
Collector	Urban	all	all			0.85	2%			yes	no	0.40

Example – Computation of Default Capacities by Functional Class and Area/Terrain Type

Functional Class	Area Type	Terrain Type	Lanes	Ideal Cap	PHF	Fhv	FW	Fdir	Fno-pass	Fpark	Fleft	Fcbd	g/C	Cap/Lane
Freeway	Rural	Level	all	2400	0.85	0.98								2000
		Rolling	all	2400	0.85	0.91								1900
		Mountain	all	2300	0.85	0.80								1600
	Urban	all	all	2300	0.90	0.98								2000
Divided Arterial	Rural	Level	>2	2200	0.85	0.98								1800
		Rolling	>2	2100	0.85	0.91								1600
		Mountain	>2	2000	0.95	0.80								1400
	Suburban	all	all	1900	0.90	0.98				1.00	1.10	1.00	0.45	850
	Urban	all	all	1900	0.90	0.98				0.90	1.10	1.00	0.45	750
	CBD	all	all	1900	0.90	0.98				0.90	1.10	0.90	0.45	650
Undivided Arterial	Rural	Level	2	1400	0.85	0.95	1.00	0.97	1.00					1100
		Rolling	2	1400	0.85	0.83	1.00	0.97	0.93					900
		Mountain	2	1400	0.85	0.65	0.80	0.97	0.81					500
	Suburban	all	all	1900	0.90	0.98				1.00	1.00	1.00	0.45	750
	Urban	all	all	1900	0.90	0.98				0.90	1.00	1.00	0.45	700
	CBD	all	all	1900	0.90	0.98				0.90	1.00	0.90	0.45	600
Collector	Urban	all	all	1900	0.85	0.98				0.90	1.00	1.00	0.40	550

Computing average speed

The updated BPR formula is as follows:

$$s = \frac{s_f}{1 + a\left(\frac{v}{c}\right)^b}$$

where: *s* = predicted mean speed
s_f = free-flow speed
v = volume

$c = \text{practical capacity}$
 $a = 0.05$ for facilities with signals spaced 2 mi apart or less
 $= 0.20$ for all other facilities
 $b = 10$

Many regions have modified the parameters a and b so that the formula calculates speeds that more closely reflect observed local speeds. The original BPR formula uses $a = 0.15$ and $b = 4$. Other regions have used values of a as high as 1.0 and values of b as high as 11.

- Advantages**
- Able to produce highly accurate speed estimates if applied properly.
 - Accounts for future congestion impacts on speed.
- Limitations**
- In order to produce accurate speed results, requires accurate local information on capacity and free-flow speed. Use of default look-up tables for these values often leads to inaccurate speed estimates.
 - To apply this method for individual links, requires detailed information regarding signalization characteristics, traffic characteristics, etc.
- Example Location**
- Ohio DOT used the original form of the BPR formula ($a = 0.15$ and $b = 4$) to estimate speed in rural areas not covered by a TDF model. To estimate free-flow speeds, Ohio DOT used the upper bound of the table provided in the HCM for each functional class.