September 8, 2003

The Honorable Peter Shapiro
Chairman
National Capital Region Transportation Planning Board
Metropolitan Washington Council of Governments
777 North Capitol Street, NE, Suite 300
Washington, DC 20002

Dear Chairman Shapiro:

This letter is the first report of the Transportation Research Board's (TRB's) Committee for Review of Travel Demand Modeling by the Metropolitan Washington Council of Governments (MWCOG). The committee, appointed by the National Research Council to undertake this review, includes both scholars and practitioners, who collectively are familiar with MPO modeling practices in many areas of the country. The committee's membership is listed in Attachment 1.[1]

In a letter of May 8, 2002, Mr. Phil Mendelson, acting as Chairman of the National Capital Region Transportation Planning Board (TPB, a constituent unit of the MWCOG), requested the TRB to undertake this study. That request describes the present study as part of the TPB's ongoing program to upgrade its travel forecasting methods and respond to federal guidance on modeling in air quality nonattainment areas.

The study's scope is described in the Statement of Task approved by the Governing Board of the National Research Council on October 9, 2002. The Statement of Task is Attachment 2.

That Statement of Task specifies the committee will "perform review of the state of the practice of travel demand modeling by the Transportation Planning Board (TPB) of the Metropolitan Washington Council of Governments" to provide guidance on five specific elements listed in the statement. This letter addresses primarily the first two items:

- The performance of the TPB's latest travel model (version 2) in forecasting regional travel, and
- The proposed process for merging the latest travel model outputs to produce mobile source emissions.

A second letter will be prepared later in the year to address other items raised in the Statement of Task and certain issues raised in this letter.

Our intent in this study is to assess the framework and methods that underlie TPB's models

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[1] Biographical information is available at www4.nas.edu/webcr.nsf/CommitteeDisplay/SAIS-P-02-07-A?OpenDocument

and their application within the context of the current "state of practice." The committee's observations presented in this letter report have been reviewed independently under the procedures of the National Research Council by individuals selected for their diverse perspectives and technical expertise.

In the course of our deliberations, committee members examined public documents prepared by the TPB and others, met as a group and by teleconference, and held a face-to-face meeting and teleconferences with TPB staff. The committee invited presentations at their first meeting from other interested parties as well as TPB. (See Attachments 3 and 4.) Following each meeting, the committee posed questions to TPB staff and requested supplemental information to gain greater understanding of the agency's models and forecasting procedures. TPB staff responded promptly to these requests.

We begin by stating our principal observations and then proceed to explain the basis for our conclusions. We open each section with a description of our understanding of the background issues underlying the study, which has been the context for our discussions. The letter then presents the committee's observations on the TPB's travel-demand modeling procedures related to air-pollution emissions analyses. We consider the structure and logic of the models and then turn to how they are applied by the TPB. Because of the complexity of the presentation, we have included a table of contents for the letter as Attachment 5.

Principal Observations

Although travel demand models have been used in transportation planning for some four decades, there are few universally accepted guidelines or standards of practice for these models or their application. Similarly, the methods metropolitan planning organizations (MPOs) employ in reformatting and otherwise modifying data produced by their travel models for use in mobile-source emissions estimation—*postprocessing*—are varied and typically change as each new generation of the emissions model enters current practice (MOBILE6 is the most recent). The committee observes that any assessment of these models and their performance must rely primarily on professional experience and judgment.

The committee's findings are based upon its experience in regions with populations, institutional complexity, travel patterns, and air quality planning requirements comparable to those of the metropolitan Washington area. No two metropolitan areas are the same however, and the committee has had neither time nor resources to conduct comprehensive statistical comparisons among regions. Within the Washington area, transportation planning is carried out in an environment characterized by rapid growth and growing congestion, a knowledgeable and politically active population, and the sometimes competing interests of three states and some 20 local governments comprising the TPB's constituency. In the context of this complex political and environmental setting, the committee observes that the TPB staff are quite open in discussing their travel modeling practices.

The committee makes the following points regarding the performance of TPB's travel demand models:

1. TPB's travel model set is based on the four-step representation of travel demand that is widely adopted in current U. S. practice. The most recent TPB version of these models—the "COG/TPB Travel Forecasting Model, Version 2.1/TP+, Release C"— is generally typical of how these models are implemented by MPOs (see page 9).

2. As has become common practice among MPOs, TPB's use of locally gathered household survey data to develop estimates of trip rates and trip lengths for travel model development and calibration is preferable to the use of national census data or travel surveys for these purposes (see page 10).

3. Statistical measures indicate that base-year modeled link volumes do not match observed traffic counts and transit ridership as closely as committee members would typically expect in model validation (see page 10).

4. MWCOG's consensus-based method for projecting regional distributions of population and employment is similar to practices used by many other MPOs (see page 11).

5. TPB's inclusion of the home-based shopping trip (HBS) category in trip generation is commendable. Combining business and commercial trips in the non-home-based trip (NHB) category is not advisable (see page 12).

6. The use of fixed bus speeds in TPB networks may misstate the influence of transit in estimates of future trip distribution and mode choice (see page 13).

7. TPB's extensive use of adjustment factors in trip generation, trip distribution, and mode choice to enhance the match between simulated and observed base-year data undermines the fundamental behavioral logic of the four-step modeling process (see pages 13, 14, and 15).

8. TPB's feedback of highway and transit times to trip distribution bypasses mode choice and is not typical of good modeling practice in regions with significant transit services and ridership (see page 16).

With regard to postprocessing procedures for preparing inputs for the MOBILE6 model,

9. TPB's disaggregation of VMT into detailed vehicle classes is similar to the procedures used by some MPOs, as is the estimation of off-network VMT. The agency's frequent updating of vehicle registration data is commendable (see page 17).

10. The TPB's procedure for estimating hourly traffic volumes and speeds—aggregation of peak- and off-peak period traffic assignments to a 24-hour total that is then redistributed to hourly periods—is questionable, because the final emission estimates

are not strictly based upon assigned peak and off-peak link volumes and speeds. Testing will be needed to determine the procedure's effects on emissions estimates (see page 19).

11. TPB's procedures for estimating emission rates are for the most part comparable with those of other major MPOs. The development of weighted emissions rates reflecting county-level travel patterns is commendable (see page 22).

Background

TPB is the designated MPO for the local government jurisdictions of the three-state Metropolitan Washington area. MPOs are responsible for preparing plans and programs for federally funded transportation investments in the regions they serve. Among the matters MPOs routinely consider in developing their plans is the consequence of proposed improvements for their regions' air quality.

Travel Demand Simulation for Transportation System Planning

The U. S. Department of Transportation (DOT) bases project funding on long-range transportation plans (LRTPs), typically for 20 years or longer, and short-range transportation improvement programs (TIPs) that MPOs have adopted. The TPB terms its LRTP the "financially Constrained Long-Range Transportation Plan" (CLRP), describing the CLRP as

> ... a comprehensive plan of transportation projects and a system-wide collection of strategies that the TPB realistically anticipates can be implemented over the next 25 years. Federal law requires the TPB and other MPOs around the country to update their long-range plans every three years. In practice, the TPB has typically amended the CLRP every year, along with developing a new Transportation Improvement Program (TIP). A new air quality conformity determination must be made when the CLRP and TIP are amended unless only conformity-exempt projects are added.[2]

MPOs rely on sets of computer-based mathematical *travel demand models* to forecast the levels of vehicular traffic that may occur if the LRTP and TIP are implemented. The models incorporate projected demographic and economic changes in the region, characteristics of the region's transportation system, and proposed changes in transportation facilities and operating policies, as well as assumptions about the factors influencing peoples' decisions about when, where, and how they will make trips. Data are used during *calibration* to estimate model parameters that characterize travel behavior; that is, relationships are developed between travel characteristics in a region and the demographic, land use, and transportation system attributes of the region. The ability of an MPO to effectively capture these relationships is vital to good forecasting performance of the models. The models are then *validated* by

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[2] As reported on TPB's web site (www.TPB.org/transportation/activities/clrp/). The committee noted that such frequent updating is unusual among MPOs.

comparing aggregate indicators of simulated regional travel patterns[3] in a base year to observed travel. Interviews of trip makers, census journey-to-work tables, road traffic counts, and transit ridership statistics are widely used sources of base year data for model calibration and validation. It is not unusual for modelers to judiciously adjust model parameters during validation to more closely simulate observed travel, within the logical framework imposed by the models' underlying assumptions.

The models most MPOs use embody similar logic and assumptions, but each MPO tailors its models and their application to the region's particular characteristics, available data and other resources, and the preferences and knowledge of the people responsible for operating and maintaining the model set. As a result, the views of modeling practitioners on appropriate practices vary somewhat. Although federal and state transportation agencies and practitioner and advocacy organizations have encouraged particular modeling practices,[4] the committee observes that there are no widely accepted guidelines explicitly delineating "best" practices or setting standards of practice for travel demand modeling.

Travel Model Simulations in Mobile-Source Emissions Estimation

Forecasts of future travel are also used to estimate the consequences that system investment and operating decisions will have on mobile-source emissions in a region. A particular concern of MPOs in regions that have been designated by the Environmental Protection Agency (EPA) as air quality non-attainment or maintenance areas[5] is determining whether their regional transportation plans and programs conform to State Implementation Plans (SIPs) for meeting national air quality standards. Under EPA's "conformity" requirements, if estimated emissions resulting from forecasts of future vehicle travel exceed the emission budgets established in the SIP, the Federal Highway and Federal Transit Administrations will not continue to provide funding for transportation improvements other than certain exempted projects.

TPB staff conducts the analyses that are used to develop and assess the conformity of its region's transportation system development plans and improvement programs. The Clean Air Act Amendments of 1990 (CAAA) designated the metropolitan Washington region a "serious" non-attainment area for ozone and as a "non-attainment" area for carbon monoxide (CO). EPA subsequently reclassified the area as "severe" for ozone non-attainment and as a "maintenance" area for CO.[6] TPB staff must therefore conduct conformity analyses to demonstrate that anticipated mobile-source emissions resulting from implementation of the region's transportation system plans will not exceed emissions budgets established under the

[3] Commonly used indicators include total person- and vehicle-trips within major travel corridors or across cordons or screenlines dividing, for example, central area from suburbs, or north from south, and total estimated vehicle-miles of travel (VMT) in the region or major subregional areas.
[4] For example, Ismart, Dane, *Calibrating and Adjustment of System Planning Models,* Federal Highway Administration, U.S. Department of Transportation, December 1990 (ntl.bts.gov/DOCS/377CAS.html).
[5] That is, under the terms of the Clean Air Act Amendments of 1990.
[6] The final notice was published in the *Federal Register* (Volume 68, Number 16), January 24, 2003 (fr24ja03-15).

SIP. TPB staff report that a new attainment plan is being prepared to respond to EPA's reclassification.

Determining conformity with SIPs requires forecasting of emissions associated with estimated future vehicular traffic.[7] EPA specifies that the MOBILE model be used to estimate future mobile-source emissions. The current version is MOBILE6.[8] The parameters of travel estimates produced by most applications of travel models—primarily traffic volumes and link travel times on specific road links—cannot directly be used with MOBILE6 and typically undergo additional processing (i.e., *postprocessing*) to make them usable. As with travel demand modeling, the exact procedures that MPOs use to produce the input data needed for emissions estimation and conformity analysis may differ from region to region.

EPA's conformity requirements assert that travel models must meet six criteria:[9]
(1) validation against observed travel and assessment of the reasonableness of forecasts in view of past trends; (2) documentation of model assumptions about land use, population, and employment, to be based on best available information; (3) incorporation of future land development and use assumptions consistent with future transportation system alternatives; (4) use of a capacity-sensitive assignment methodology that distinguishes peak from off-peak link volumes; (5) incorporation of feedback of travel times resulting from traffic assignment to times used in trip distribution; and (6) reasonable sensitivity to changes in travel times, costs, and other factors affecting travel choices.

Commenting on the conformity requirement and its implications for travel modeling, FHWA states[10]

> EPA believes that areas must use the most current tools available at the time of the conformity determination, in accordance with the Clean Air Act. Using the best models and assumptions will also produce the best emissions estimates on which areas will base decisions regarding transportation and air quality.

FHWA notes also that "EPA believes that ... the retaining of these criteria" (i.e., in the agency's final rulemaking) "establishes minimum acceptable practice."

In the absence of authoritative criteria, modeling professionals may differ in their opinions of what constitutes standard practice, "best models and assumptions," or experimental practices

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[7] While TPB considers emissions in developing its plans and is responsible for making the required conformity determination, another MWCOG board prepares the requisite emissions forecasts upon which the determination is based.
[8] Except in California, where the EMFAC2 model is used.
[9] "VIII. Deadline for Use of Network Models and Affected Areas," and "IX. Content of Network Modeling Requirements in Serious and Above Ozone and CO Areas," *Federal Register*, August 15, 1997 (62FR158, 43790-43795).
[10] *Specific Regional Analysis Requirements, Chapter 6 Serious and Above Ozone and CO Non-attainment Areas*; FHWA (www.fhwa.dot.gov/environment/conformity/ref_guid/chap6.htm).

that may or may not someday become standard.[11] In this study, the committee is relying on its members' perspectives, based on their experience in other regions of the country that may be considered comparable to the metropolitan Washington area, in terms of scale and complexity of travel patterns to be simulated and issues of air quality.[12] Large size, rapid growth, and multi-state political structure arguably make travel forecasting more complex and increase an MPO's susceptibility to challenges from its many diverse constituents.

Meaning of Performance

Within the context of the two purposes travel models must serve—support for decisions about system investment and operating policies and support for analyses related to mobile-source emissions estimation—committee members suggested two criteria to judge whether an MPO's travel models may be said to perform well:

- The models' internal structure and application of available data comprise a logically plausible explanation of the region's travel patterns, in terms of the principal parameters and the relations among these parameters that shape those patterns; and
- The models produce estimates of future regional travel that reflect logical responses of travel patterns to changes in transportation system configurations and operating policies.

The first criterion is crucial, because it refers to the models' fundamental portrayal of the reasons that travel occurs in the ways that it does. As discussed in later sections of this report, observed base-year traffic volumes and transit ridership are compared with quantities simulated by the models to validate the models. A model set's ability to match observed quantities is an important indicator of the set's quality. Validation assures that modelers can confidently say that the models are a meaningful representation of the transportation system. Adjustments made to models to improve their ability to replicate base-year observations but which do not reflect reasoned representation of factors influencing travel demand or supply, reduce the models' credibility.

The committee considered both criteria in its discussions, but the emphasis was primarily on the first. Whether a model set well represents the system's likely response to configuration and operating policy changes is a primary concern of any MPO and its various stakeholders in plan development. Although TPB's most recent models have been subjected to considerable scrutiny by agency staff and technical committees, experience with their use in plan development is limited. Recognizing this history and that the models are generally representative of the models used by many MPOs, the committee focused its attention on

[11] See, for example, Replogle, M., *et alia*, Letter to Mr. P. Mendelson and Ms. Hanley, Re: Effects of Proposed Potomac River Crossings on Land Use and Traffic and Identification of Serious Deficiencies in TPB Version 2 Transportation Model; November 4, 2002. Replogle, M., Letter to Mr. R. Kirby, Re: Response to November 20, 2002 letter from Ron Kirby to Michael Replogle regarding deficiencies in TPB Version 2 Transportation Model; January 22, 2002 (*sic*).

[12] The committee did not attempt to identify a rigorously defined agency peer group, but the committee's members agreed that TPB's practices may be appropriately compared with those of MPOs in, for example, Boston, Chicago, Dallas/Ft. Worth, Miami, Philadelphia, Phoenix, and other regions.

details of the models' internal structure, logic, and uses of data to represent regional travel patterns. As TPB proceeds with development of new LRTPs and TIPs, agency staff will presumably use measures such as the following to assess the models' performance in forecasting:

- Rates of change in transit boardings by line compared with historic rates of change,
- Rates of change in highway link volumes and speeds compared with historic rates of change,
- Changes in mode shares compared with historic mode shares, and
- Transit line volumes and park-and-ride lot usage compared with estimated facility capacities.

TPB's Travel Models and Forecasting of Regional Travel

TPB, like most MPOs,[13] uses models based on a four-step travel forecasting process. These models are used to

- Estimate the total number of trip productions and attractions in a time period (e.g., an average 24-hour weekday) associated with a transportation analysis zone (TAZ);
- Project the distribution of trip ends between production and attraction zones, which are then factored into TAZ origin-destination trip tables;[14]
- Estimate the fractions of trips that will choose each available mode of travel between origin and destination zones; and
- Project the specific routes trip will follow between zones, yielding traffic volumes on *links* in coded regional transportation networks.

Each step of the four-step process will often entail the use of several sub-models, for example, to address differences in travel behavior and system characteristics by time of day, for different classes of vehicles, or for toll and high-occupancy vehicle (HOV) network links. The final results are estimated directional passenger and vehicle volumes on each link during some specified period of time.[15]

A consequence of modeling travelers' choices of destinations, modes, and routes in the strictly sequential manner represented by the four-step process is that these choices depend on the performance of the transportation system, which cannot be estimated until these choices are modeled. Modelers typically incorporate feedback between the four sequential steps of travel demand model systems to ensure numerical consistency among the inputs and outputs of the various steps.

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[13] It is not within either the scope of this study or the limitation of the time and resources available to the committee to conduct a thorough review of practices of MPOs around the country. In both this letter and its deliberations generally, the committee is relying primarily on members' experience and judgment.
[14] Trips specified by both origin and destination are also termed "origin–destination interchanges"*;* trips specified by both production and attraction are termed "production–attraction interchanges."
[15] Traffic may be specified in several vehicle classes, e.g., autos, heavy trucks.

The Travel Model Set

TPB's current model set, designated as the "COG/TPB Travel Forecasting Model, Version 2.1/TP+, Release C" and referred to as the Version 2.1/TP+ model, is "a translation of the MINUTP-based Version 2 model."[16] Release C of the Version 2.1/TP+ model was issued for review and use in December 2002.[17] That release, the basis for the committee's review, remains in draft pending update of the region's SIP and analysis of conformity of the CLRP and TIP to the SIP. The committee observes that this type of software is widely used by MPOs to develop their travel demand models.[18]

Data and Assumptions for Calibration and Validation

TPB's travel demand forecasting process includes public discussion of assumptions and modeling procedures and participation by a broad range of stakeholders who regularly attend meetings of the TPB and its various topic-area committees. The periodic meetings of the Travel Forecasting Subcommittee, generally responsible for technical matters related to selection and application of the TPB's travel demand models, are open to the public; TPB's records show that participants regularly include consultants, representatives of local, state, and federal agencies, and other professionals, as well as members of the TPB staff. Such openness is meant to increase understanding among decision makers and the general public of the issues, uncertainties, options, and consequences inherent in the evolution of a region's transportation system and to provide a forum for discussion of the travel demand models and their application.[19]

Surveys of traveler behavior and counts of traffic or passenger volumes on the region's roads and transit system are principal sources of data most MPOs use in model calibration and validation. The 1994 Household Travel Survey (HTS) of 4,863 households is the basis for much of TPB's analysis. Traffic counts on selected roads are provided to TPB by the departments of transportation of Maryland, Virginia, and the District of Columbia. The Washington Metropolitan Area Transit Authority and other public agency operators provide transit ridership data.

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[16] TP+ is a commercially available package that provides, according to its vendor, "a general framework for implementing a wide variety of travel demand forecasting processes encompassing simple 4-step models to the most advanced travel models requiring thousands of zones and the most advanced features...." offering users "flexibility and the ability to formulate a wider variety of model structures" (http://www.citilabs.com/tpplus/index.html).

[17] *COG/TPB Travel Forecasting Model, Version 2.1/TP+, Release C, Calibration Report*, draft, TPB, December 23, 2002.

[18] New software packages under development may significantly reduce the levels of staff effort and computational resources required in travel demand modeling.

[19] For example, TPB meeting records show that as early as May 17, 1996, representatives of a coalition of environmental groups, led by Environmental Defense, expressed concerns about the specific results of travel forecasts and proposed that different models might be needed to more effectively forecast travel by non-motorized modes (e.g., bicycle and pedestrian).

Bases for Estimating Trip Rates and Length

The 1994 HTS is TPB's primary source of information for estimating trip production and attraction rates and trip lengths. Other potential sources of recent travel data are the periodic Nationwide Personal Travel Survey (NPTS), now known as the National Household Travel Survey (NHTS), and the census journey-to-work data. The NPTS and NHTS are based on a relatively small sample of households and factored to represent the nation as a whole. These surveys include only a handful of observations in the TPB area. Some MPOs have chosen to conduct "add-ons" to the survey to expand the sample in their regions. It is worth noting that the census includes only work-trip data, and the nature of the census journey-to-work questions are such that these data are difficult to factor to the typical workday simulated by the TPB models. In addition, NPTS/NHTS survey procedures have changed from time to time, making longitudinal comparisons more difficult. The committee observes that locally gathered data such as the TPB household surveys is preferable to national census data or travel surveys as the primary basis for travel model development and calibration.[20] However, the NPTS/NHTS may be a useful source of data for cross-checking local survey results, for example the possible under-reporting of non-home-based travel in the 1994 HTS.

Goodness of Fit for Vehicle Traffic Volumes

A key criterion of successful model validation is "goodness of fit" to observed traffic volume counts, typically indicated by the root mean squared error (RMSE) statistic. RMSE is computed by comparing observed traffic and simulated link volumes for the base-year and is expressed as a volume (e.g., vehicles per hour or day, vph or vpd) or a percentage of volume on the link (%RMSE).[21] Larger numbers for either statistic indicate greater errors in a model's ability to simulate observed conditions. TPB reports these statistics for the overall model and for highway links classed by volume. TPB indicates the year 2000 average %RMSE for all facility types and volume classes in the regional network was about 51 percent, a level that TPB found acceptable in view of other indicators of model validation. Reported RSME measures indicate that base-year modeled link volumes do not match observed traffic counts as closely as committee members would typically expect in model validation. For example, the committee found that for 8 of 33 traffic volume classes, RSME values were only marginally acceptable, on the basis of literature and the committee's experience.[22]

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[20] The committee is aware that some observers argue that data gathered at a national scale gives more representative samples for characterizing travel behavior when, for example, significant changes in a region's transportation system are to be considered. The committee does not find such arguments persuasive.

[21] RMSE typically is also computed for traffic crossing cordons or screenlines and for the network as a whole. TPB staff report that they rely particularly on screenline traffic volumes for model validation, rather than link volumes. Other measures of goodness of fit include the ratio of simulated to observed trips between TAZs or districts and the correspondence between simulated and observed distributions of trip times reported by individuals using the system.

[22] Refer, for example, to *Model Validation and Reasonableness Checking Manual*, February 1997, prepared for FHWA by Barton-Aschman Associates, Inc., and Cambridge Systematics, Inc., especially Chapter 7 (http://tmip.fhwa.dot.gov/clearinghouse/docs/mvrcm/ch7.stm), or *Travel Demand Forecasting Manual 1, Traffic Assignment Procedures* by Gregory Giaimo, PE, Ohio Department of Transportation, Division of Planning,

Goodness of Fit for Transit Passenger Volumes

Materials TPB provided to the committee indicate that the agency's models produce systemwide underestimates of transit trips in the range of 5 to 8 percent.[23] The committee would expect to see a closer match between the estimated and observed ridership figures, for a major metropolitan area with significant transit ridership. The goodness of fit for transit passenger volumes is normally conducted in more detail than systemwide averages and cordon crossings. Additional comparisons by subarea, district interchange, corridor, and rail line and station are typically performed to ensure that usage, trip distribution, and travel patterns by transit are reliably replicated by the model for regional planning purposes. The committee is concerned with the performance of the model with respect to transit estimates and validation.

Travel Modeling

TPB makes frequent use of their travel models in developing and updating its regional plans and programs. Other agencies use these model results and sometimes the models themselves as components of their own planning and decision making.[24]

Future Distributions of Employment and Households

Distributions of employment and households within the region are key parameters for estimating the numbers of trips made, in the trip generation step of simulation. Census data updated on the basis of such information as building permits provides the basis for model calibration and validation.

MWCOG's constituent jurisdictions participate in a cooperative, consensus-driven process to develop estimates of current and future distributions of employment and households, within the constraint of regional totals from census data and forecasts by a regional economic model. This cooperative forecasting method yields estimates at the small-area (TAZ) level that TPB then uses in travel demand forecasting. While computer-based land use models[25] are widely applied for this purpose, the committee observes that many MPOs rely on a consensus-based method for their projections of future distributions of employment and households.

Trip Types

TPB estimates person trips in four categories: home-based work, home-based shopping, home-based other, and non-home based (respectively, HBW, HBS, HBO, NHB). The

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Office of Technical Services, August 2001 (especially Chapter IV, "Assignment Limitations, Checks and Refinements").

[23] See *COG/TPB Travel Forecasting Model, Version 2.1/TP+, Release C, Calibration Report*, draft, TPB, December 23, 2002, Exhibit 9-1.

[24] For example, state and local jurisdictions use the TPB models and results as the context for making decisions about local road and transit improvements, and state governments use model results for air quality SIP preparation.

[25] Such models use assumptions about the region's future economic structure, transportation network, and land-development policies to forecast where within the region future employment and residences will be located.

committee observes that many MPOs use the initial three categories. The committee agrees that inclusion of the HBS category is a commendable practice.

TPB subsumes business and commercial trips made by light-duty trucks (e.g., all pickups and panel trucks) in the person-trip tables.[26] The committee observes that commercial-vehicle and household-based person trips have different time-of-day distributions and are associated with fundamentally different types of activities.

Separate modeling of commercial travel in the four step process has been adopted by some agencies in the past decade,[27] but lack of data and issues of confidentiality in commercial data have constrained the ability of models to produce reliable results. Some professionals assert that explicitly modeling commercial trips can correct the underestimation of travel that is common when using a model based solely on home interview survey data. TPB explicitly models commercial trips made by medium- and heavy-duty trucks. The committee intends to review this model in the study's second stage.

Factoring of Productions and Attractions

Since household trip production and trip attraction models[28] are calibrated separately, there may be an imbalance between trip productions and attractions after completing trip generation. This imbalance may persist even after adjusting productions and attractions for trips entering and leaving the region. At this point, modelers will sometimes adjust or factor trip productions and attractions to obtain a region-wide balance.[29] Modelers typically try to keep the adjustments, if necessary, relatively small—i.e., the numerical values of the factors should be close to unity—unless there are clearly understood biases in the data that justify larger adjustments.

Materials TPB provided to the committee indicate that the agency develops trip generation rates on the basis of income, household size, and vehicle availability levels, and applies aggregate adjustment factors that range between 0.5 and 2.0 to improve the match between estimated and observed productions and attractions at the jurisdiction level. Because base-year trip production and attraction control totals by superdistrict[30] are determined from the 4,863-household 1994 HTS and there are 37 superdistricts delineated in TPB's models, the total number of survey observations in some superdistricts may come from fewer than 50

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[26] Many MPOs use the NHB person-trip category to include a variety of trip types, and some factor the NHB trip tables to produce a distinct commercial vehicle table. Although TPB staff explains that these light-duty trucks are used interchangeably with autos for commuting and other trip purposes, in many cases the trip types are essentially unrelated to the logic of the household travel model underlying the subsequent travel forecast. While acknowledging the TPB explanation, the committee questioned the wisdom of including all light-duty truck trips in the NHB category.

[27] Among the areas with distinct commercial-trip models are Baltimore, New York, and Columbus, Ohio.

[28] Productions and attractions refer to trip segments between pairs of TAZs. A single trip from one origin zone to a particular transportation zone may pass through intermediate zones and be modeled as a chain of productions and attractions.

[29] That is, the number of attractions or productions will be increased or decreased to impose an assumption that the region or sub-area has no substantial short-term net gain or loss of population.

[30] A sub-regional area made of multiple contiguous TAZs.

households.[31] In addition, factoring of trip productions and attractions is carried out by household income levels, which reduces the number of survey households behind the production/attraction control totals even more. Estimation errors may then be sizeable and are magnified when large factors are applied. TPB's emphasis on data fitting to observed base-year data through the introduction of mechanical adjustment factors invites the pitfalls of inaccurate and unreliable future-year travel forecasts, especially if over time there are considerable changes in demographics, land use characteristics, and transportation system attributes. The committee observes that substantial factoring of trip productions and attractions is unusual and not a good practice.

Travel Impedance and Factoring of Interchanges

TPB's zone-to-zone trip distribution procedures utilize a gravity model specification similar to that used by many MPOs. The gravity model depends fundamentally on estimated impedances.[32] Material TPB provided to the committee indicates that the agency computes impedance as a composite of highway and transit travel times. Scheduled transit times are used throughout the modeling process, rather than estimated travel times calculated from loaded highway networks.[33] Committee members noted that many MPOs in larger metropolitan areas derive bus transit speeds from algorithms that estimate transit link speed as a function of the corresponding highway link speed, usually by facility type and area type to reflect the prevailing stop density and traffic conditions. TPB's use of fixed schedule speed in estimating zone-to-zone impedances is likely to misrepresent mode choice forecasts due to the effect of highway congestion on bus transit speeds, overstating transit performance where congestion increases and understating it where congestion decreases. This could lead to improper performance evaluations of highway and transit improvements in the TPB model, especially in areas with existing or potentially large transit market shares.

The committee agreed that such practices as using schedule times for transit and including a variety of disparate trip types in a single trip-type category—as discussed regarding TPB's treatment of business and commercial light-duty truck trips—are widely adopted by MPOs, often expedient, and may introduce errors that are relatively small. These practices nevertheless contradict the fundamental premise underlying these forecasts: that the models simulate how the system operates. Establishing an appropriate balance between theoretical correctness and practical limitations of data, time, resources, and the concerns of stakeholders is a problem common to all modeling efforts.

Impedances are sometimes modified for groups of zones (districts) by the application of "K" factors to account for influences not readily measurable by distance, travel time, or direct

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[31] TPB staff report the range of observations is 16 to 363, with mean of 131.46 and median 135.

[32] The gravity model assumes that the likelihood that an interchange produced in one zone will be attracted to another zone varies as the product of the numbers of productions and attractions estimated for the two zones and inversely with the impedance between the two. Impedance is a composite measure of the distance, travel time, or direct costs associated with making a trip between points within two TAZs or a single TAZ.

[33] TPB estimates times for auto access to transit from restrained highway times produced in the assignment stage. Some agencies, e.g., Seattle's MPO, use a logit-based park-and-ride model. We will consider such matters in the second stage of our study.

costs. Such factors are typically felt to be justifiable when applied to interchanges across jurisdictional boundaries, major physical barriers such as rivers, or perceived barriers associated with socio-economic differences within a region, conditions found in abundance in the Washington region.

Materials TPB provided to the committee indicate that the agency does make extensive use of K factors to adjust intra-zonal, inter-zonal, and inter-district trip interchanges; some of these factors are applied as time penalties to adjust traffic flows on Potomac River crossings, while others are used to adjust travel times within jurisdictions. However, committee members were concerned that the fraction of inter-zonal pairs to which K factors are applied is inordinately large, in comparison with river crossings and other apparent sources of distortions in the region's travel patterns, and agreed that such extensive application of K factors is inadvisable.[34] K factors can improve a model's overall goodness of fit in validation and their sparing use is not uncommon in modeling practice.[35] There is, however, little theoretical basis for anticipating that these K factors—even those associated with clearly definable travel obstacles unrelated to factors included in typical impedance measures—will remain constant in future years. The use of K factors is a subject of active, continuing debate among modeling professionals.

Transit Travel Times and Mode-Choice Probabilities

Transit use in the metropolitan Washington region is relatively high, compared with other regions of comparable size. The TPB mode choice procedures entail distinctly specified models for each of the four trip purposes, applied to allocate trips among transit, drive-alone auto, and group-ride auto modes. HBW auto-related trips are further allocated to distinguish between auto trips using High-Occupancy Vehicle facilities and low-occupancy vehicle trips that do not use such facilities. In estimating mode choice, as with trip distribution, TPB uses scheduled transit travel times rather than congestion-adjusted times to represent transit speeds.

Materials TPB provided to the committee indicate that the agency applies adjustment factors to simulated mode shares, apparently to improve the match between base-year observed and simulated transit trips summarized at the jurisdiction level. Committee members conjectured that these factors could shift projected aggregate future transit patronage by 5 to 10 percent and seemed in some cases to imply unreasonably high probabilities of transit usage.[36] The committee finds these adjustments in mode choice to be further evidence (i.e., with trip factoring and extensive K-factor use) of TPB's efforts to improve the statistical fit between

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[34] A report from FHWA has advised more strongly, "K factors do not remain constant over time and are generally discouraged." (Ismart, *op cit.*, page 22).

[35] At the committee's request TPB prepared a limited analysis of the sensitivity of link volumes to the application of K factors, by comparing model runs made with and without the TPB's factors. To understand more completely the consequences of factoring, it would be useful for TPB to test its models without K factors and conduct further sensitivity analyses.

[36] Committee members examining TPB materials found instances in which the adjusted number of transit trips implied a probability that a trip between two particular zones would exceed 100 percent, i.e., adjusted transit trips exceeded total interchanges. It appears that TPB is applying adjustments to probabilities rather than model utilities. The committee intends to consider this matter further in the second stage of the study.

base-year data and simulations rather than capture underlying travel behavior relationships; such data-fitting emphases weaken a model's ability to provide defensible forecasts.

The committee recognizes that modelers will have multiple objectives in their calibration and validation work. The models must simulate operations in the base year to satisfy stakeholders that the models are a useful representation of the system. The models must also produce defensible forecasts of future travel. Both these objectives are achievable.

Route Assignment

TPB allocates daily modal trip tables among morning and evening peak and off-peak time periods and then assigns the individual time-period trip tables to the highway networks. Road-link capacities are defined by traffic level of service "E." Materials TPB provided to the committee indicate that the computational procedures are not different for peak or off-peak periods.[37]

Feedback in Model Application

Materials TPB provided to the committee indicate that the agency's models do not include explicit feedback of projected highway travel times and costs in the mode-choice stage. TPB employs restrained travel times from an initial traffic assignment in applying the mode choice model, but mode choice is not executed again during feedback of subsequent traffic-assigned travel times to trip distribution.[38] Current conformity requirements for network-based modeling state that travel times from final assigned volumes should be used for modeling mode split when use of transit currently is anticipated to be a significant factor in satisfying transportation demand.[39]

The TPB models do perform feedback of peak and off-peak highway travel times into trip distribution through an impedance measure that combines highway time with a weighted transit time. The weighting used is regional transit mode share, stratified by four trip purposes and four income levels, rather than transit mode share of the zone-to-zone trip interchange. As previously noted, transit speeds are based on schedules rather than adjusted for road traffic levels, except for auto-access-to-transit travel speeds. Committee members observed that not including mode choice in feedback computations weakens the models' credibility and is inadvisable in a region with substantial transit services and ridership.

[37] Committee members observed that the number of equilibrium assignment iterations required to reach a specified approximation to equilibrium conditions in network assignment generally increases with levels of congestion in the network; i.e., peak period assignments typically require more iterations compared with off-peak assignments.
[38] The subsequently adjusted person-trip tables (by purpose), in combination with the single mode-choice model run, yield adjusted trip tables for drive-alone and group-ride auto modes for each trip purpose.
[39] *40/CFR 93.122*, as amended by *62 FR 43814*, August 15, 1997.

TPB's Postprocessing Strategy for Mobile-Source Emissions Analysis

Travel models are designed primarily to produce forecasts of traffic volumes and transit ridership that can be compared with system characteristics to judge whether the system is capable of meeting projected travel demand. Emissions forecasting using the MOBILE6 model relies on estimates of future VMT organized by classes of vehicles operating in the system, the speeds those vehicles travel, and seasonal and diurnal timing variations in travel; also, the vehicles classes used in conformity analysis differ from those that typically have been used in travel modeling. Postprocessing of travel-model outputs is the way in which TPB and other MPOs bring their travel models and MOBILE6 together for emissions forecasting.

The Postprocessor

EPA's adoption of the MOBILE6 model has required MPOs to adjust some of their postprocessing procedures. TPB is developing new modeling software, the "Version 2.1/TP+/MOBILE6 Emissions Post-Processor" or, simply, *the postprocessor*. Committee members reviewed the computer code for the postprocessor as well as narrative descriptions of the procedures and assumptions embodied in the code.

Applying Postprocessing in Emissions Estimation

EPA has published analyses intended to identify input parameters in MOBILE6 that have greatest importance for emissions estimates.[40] Parameters judged to have major importance were those that produced increased emissions of one or more modeled pollutants at least proportional to a 20 percent change (arbitrarily selected) in the input parameter. Materials TPB provided the committee indicate that several parameters found to have major importance in the analysis are inputs to TPB's postprocessing model (Table 1).

Table 1. Postprocessor Input Parameters Having Major Effect on MOBILE6-Based Emissions Estimates, for Three Primary Pollutants, Influenced by Travel-Model Output (Giannelli, *et al.*, 2002; see footnote 40)

	Pollutants		
	HC	CO	NOx
Input variables, in order of significance of impact*	Registration Distribution Average Speed Min/Max Temperature Speed-VMT (arterials)	Average Speed Min/Max Temperature Registration Distribution	Average Speed Min/Max Temperature Registration Distribution

* Variables used in TPB postprocessing model.

Registration Distribution refers to the fraction of vehicles over 13 years of age in the fleet of registered motor vehicles; older vehicles have higher emissions rates (grams of pollutant per

[40] Giannelli, R.A., J.H. Gilmore, L. Landman, S. Srivastava, M. Beardsley, D. Brzezinski, G. Dolce, J. Koupal, J. Pedelty, G. Shyu, Sensitivity Analysis of MOBILE6.0, Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, EPA420-R-02-035, Washington, D.C., 2002. The report notes that input parameters were analyzed in terms of their individual effects; combined effects may be greater or smaller. Emissions of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (Nox) are modeled. Importance is determined by a ratio of emissions change to input change greater than unity.

mile of travel) than newer vehicles of the same type. A 20 percent increase in the numbers of older vehicles in the fleet yields as much as a 50 percent increase in HC or CO emissions depending on calendar year analyzed. Emissions rates are a function also of *Average Speed* of a vehicle; 20 percent change in the fraction of vehicles traveling at lower speeds can cause 20 to 50 percent increase in CO or NOx emissions. The *Speed-VMT* variable is an array giving the fraction of vehicle-miles estimated to occur within each of the 14 speed ranges used by MOBILE6; e.g., changing the proportion of VMT associated with vehicles traveling at low speeds by 20 percent can increase HC emissions 21 percent. The *Min/Max Temperature* variable adjusts the emission rates (which are applied to hourly traffic volumes) for temperature, with colder temperatures especially influencing HC emissions rates; 5 percent temperature shift, for example, can produce 5 to 15 percent shift in HC emissions.

Estimating future emissions (the *emissions inventory*) requires using these and other variables to develop emissions-rate estimates and then applying these estimated emissions rates to the estimated future VMT derived from the travel demand model. The calculations may require consideration of the geographic or jurisdictional distribution of VMT to reflect differences in fleet composition and mileage; this also is part of TPB's postprocessing procedures.

Vehicle Fleet Mix, Registration Distribution, and VMT by Vehicle Class

To develop MOBILE6 emission rates estimates, the user specifies the proportion of vehicle miles of travel in 28 vehicle classes.[41] Materials TPB provided to the committee indicate that the agency's procedure for simulating VMT by vehicle class has three steps: 1) local vehicle registration data are used to estimate proportions of vehicles in five vehicle classes, 2) this vehicle-class distribution is combined with network travel forecasts to estimate VMT for MOBILE6's 28 vehicle classes, and 3) off-network calculations are used to estimate local-road and intra-zonal VMT (i.e., travel not assigned on the network). The committee observes that this procedure is similar to that used by some other MPOs.

In 2001, the TPB vehicle registration data were updated to reflect the region's 1999 vehicle fleet. Materials provided by TPB and otherwise available to the committee indicate that this most recent vehicle registration data included a larger fraction of sports-utility vehicles (SUVs) and heavy-duty vehicles in several jurisdictions than had previously been observed.[42,43] In November 2002, the vehicle fleet registration data were again updated to reflect 2002 information for Maryland, Virginia and the District of Columbia; TPB materials indicate that such updating is planned to proceed on a three-year cycle. The committee

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[41] TPB and other MPOs typically forecast travel for no more than five vehicle classes and frequently for only two or three classes.
[42] Harrington, W., A. Howitt, A.J. Krupnick, J. Makler, P. Nelson, S. Siwek, *Exhausting Options: Assessing the SIP-Conformity Interactions*, Resources for the Future, Washington, D.C., 2003.
[43] TPB (2001), June 29, 2002, Memo From M. Clifford to Air Quality Conformity Files, *Air Quality Conformity Determination of the 2002 Constrained Long Range Plan and the FY2003-2008 Transportation Improvement Program and the Washington Metropolitan Region*, National Capital Region Transportation Planning Board, Metropolitan Washington Council of Governments, Washington, D.C.: D19-D36.

observes that EPA and FHWA joint guidance materials[44] recommend that vehicle registration data should reflect conditions no more than five years old, and others have shown current and locally derived registration data to be a critical input to emissions estimation.[45] The committee finds TPB's more frequent updating of vehicle registration data to be commendable.

Regional estimated VMT for the two broad vehicle categories modeled by TPB, passenger and heavy-duty vehicles, are disaggregated to the MOBILE6 vehicle categories in several steps. TPB begins with current vehicle registration data (2002 in this postprocessor), collected in five vehicle categories specified in MOBILE5b (the MOBILE6 predecessor). The vehicle-frequencies distribution is then disaggregated to MOBILE6's 28 vehicle categories using MOBILE6 defaults, and adjusted by the percentages of light- and heavy-duty vehicles estimated by the TPB truck model.
As previously noted, VMT for intra-zonal (off-network) auto travel is separately calculated outside of the postprocessor. Off-network VMT includes travel associated with intra-zonal trips that are not assigned to the network plus trips on local streets that are not coded into the network except as connections to zone centroids, plus auto-access-to-transit travel. Vehicle frequencies and VMT for buses also are separately derived, using data from a survey of local transit agencies and school districts. The committee observes that these procedures are similar to those used by other MPOs.

Hourly Average Speed and VMT

Materials provided to the committee and discussions with TPB staff indicate that the postprocessing procedure aggregates the period-specific link volumes produced by the travel models to a 24-hour volume for each link. The daily volume is then redistributed to hourly volumes in several steps. First, links are categorized according to one of three default hourly distributions, based on each link's facility class and a peaking-characteristic rating (i.e., am-peak oriented, pm-peak oriented, even peaking).[46] These generic distributions are used with the aggregated total daily link volume to develop an initial distribution of hourly traffic on a link.

Next, the hourly volumes and speeds are adjusted for those hours in which the initial volume exceeds link capacity (LOS E). Beginning with peak hours (e.g., 7 to 8 am morning peak then 5 to 6 pm evening peak), projected traffic in excess of capacity is reallocated equally to the

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[44] Wykle, Fernandez, and Perciasepe, EPA and DOT Joint Guidance on Use of Latest Planning Assumptions in Conformity Determinations; January 18, 2001; www.epa.gov/oms/transp/traqconf.htm.
[45] Miller, T., W.T. Davis, G.D. Reed, P. Doraiswamy, A. Tang, Effect of county-level income on vehicle age distribution and emissions, *Transportation Research Record: Journal of the Transportation Research Board, No. 1815*, TRB, National Research Council, Washington, D.C., 2002: 47-53; Kear, T., and D. Niemeier, Sensitivity of composite exhaust emission rates to vehicle population and mileage accrual assumptions, *Transportation Research Record*: *Journal of the Transportation Research Board,* TRB, National Research Council, Washington, D.C. (forthcoming).
[46] TP, *Description and validation of the version 2.1/TP+/MOBILE6 emissions post-processor*, Draft materials presented to the travel forecasting subcommittee, March 2003, National Capital Region Transportation Planning Board, Metropolitan Washington Council of Governments, Washington, D.C.

"shoulder" hours immediately adjacent to the peak; i.e., volume projected for the 7 to 8 am peak hour is "spread" to the 6 to 7 am and 8 to 9 am hours. Revised projected volumes in excess of capacity (now possibly including traffic reallocated from a peak period) are again reallocated equally to adjacent hours, unless the adjacent hour is a peak hour; in that case all excess traffic is reallocated to the adjacent non-peak hour. Volumes in hours 1 (midnight to 1 am), 13 (noon to 1 pm), and 24 (11 pm to midnight) are not spread even if they exceed capacity.

Reallocated volumes are then used to compute hourly VMT and hourly average running speeds. The latter parameter is estimated with volume-delay relationships calibrated to the Washington region. The greater of adjusted or unadjusted volume is used to derive a conservative (i.e., lower) estimate of speed.[47]

TPB indicates that this reallocation of 24-hour daily volumes to hourly volumes accounts for the queuing and "peak spreading" that naturally occur when congestion delays travel. However, committee members suggest it may be more precise to define the problem as one of disaggregating travel estimates derived by multi-hour periods into the hourly estimates required for emissions modeling. The need for hourly VMT and speed estimates is attributable to the MOBILE6 model and the mismatch between that model's input requirements and typical travel model outputs. A variety of strategies can be used to address this particular problem, and TPB's categorizing of links by peaking patterns is not unlike probabilistic strategies that have been proposed in the literature.[48] However, the TPB's approach differs from those proposed in the literature and used elsewhere in one important feature, the aggregation of travel estimates by period to a 24-hour total and then the reallocation of volumes to individual hours.

TPB's procedure of aggregating period estimates to 24-hour volumes would seem to be inconsistent with the travel models' assumptions for estimating period-based traffic volumes and travel times that, in turn, influence trip patterns. The definition of modeling periods for the travel forecasts incorporates peaking assumptions and relationships between peaks and total 24-hour volumes. The committee agrees this use of disaggregated 24-hour volumes, as opposed to period-specific volumes produced in route assignment, is questionable because it produces emission rates that are not strictly based on peak and off-peak assignment results as directed by conformity network modeling requirements.

Speed and Emissions

Committee members noted that, whether period-specific or 24-hour volumes are spread, the impact of the peak-spreading procedure on emissions is very difficult to predict for links that

[47] TPB staff confirms that text of the TPB documentation contains a typographic error in the latter part of its explanation (page 14, paragraph 2): "The final hourly speed is computed using ... the *maximum* of the adjusted/unadjusted volumes. In other words, the congested speed is based on the lowest V/C ratio determined at any point in the volume spreading process." Higher volume would give higher V/C and lower speed.

[48] Hicks, J., D. Niemeier, Incorporating Spatial Effects in Mobile Emissions Inventories, *Transportation Research Part D*, 2001, 6(3):153-177, and Niemeier, D., Lin, K., and J. Utts, Using observed traffic volumes to improve fine-grained regional emissions estimates, *Transportation Research, Part D,* 1999, 4(5): 313-332.

are over capacity for extended periods. Committee members acknowledge TPB staff's assertions that the procedure was designed to yield more conservative (i.e., higher) estimates of emissions by projecting lower running speeds;[49] but interactions among emission rates, volumes, and speeds can cause varied results. For example, committee members used data provided by the TPB to conduct a simple illustrative analysis of the 715 freeway and expressway links on which spreading occurred.

Considering only the four hours from 6 am to 10 am, TPB's procedure does yield speed estimates conforming to TPB's expectations, i.e., initial speeds are higher than the final estimated (postprocessed) speeds (see Figure 1).

Speeds in the initial hour in which spreading occurred (8 am) are generally the same before and after postprocessing. In contrast, speeds estimated for the shoulder hours drop after postprocessing. Evidence of spreading beyond the shoulder hours can be seen in the 6 am results, where speeds drop substantially after postprocessing.[50]

To gain some insight into the potential effect of change in speeds on emissions, committee members made a simplistic assumption that the Alexandria NOx composite running emission rates, which were provided by TPB in earlier documentation,[51] could be used to approximate possible trends in emissions. Figure 2a shows the relationship of NOx emissions rate and speed. NOx emission rates are greatest on these links at lower and higher speeds.

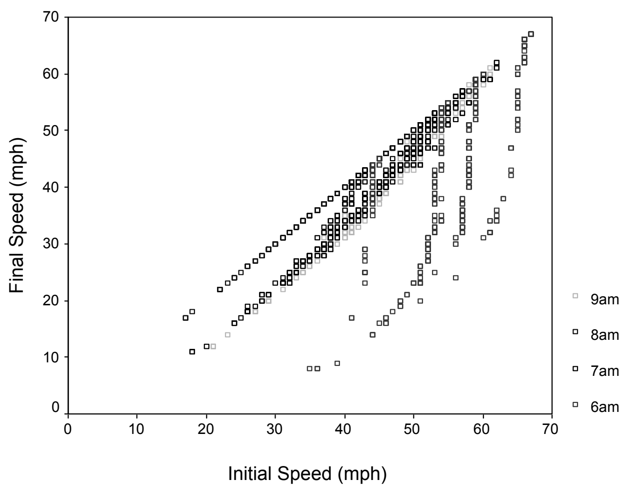
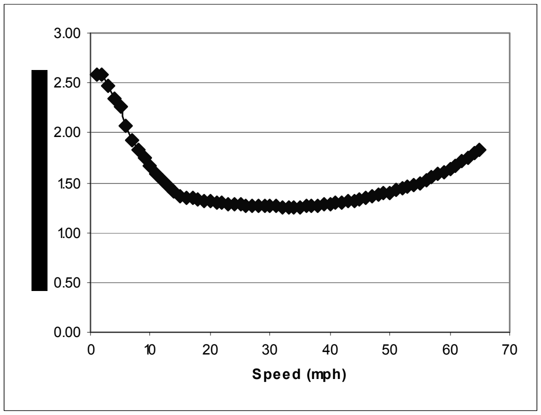


Figure 1. Freeway and expressway link speeds before (*initial)* and after (*final)* spreading.

[49] As noted, the procedure outputs the lower of the speeds before or after traffic volume has been redistributed to other hours.
[50] The committee's observations and analyses concerned speed estimates derived from the postprocessor's hourly volumes. TPB has an ongoing speed-monitoring program using aerial surveys and GPS-equipped floating cars as a basis for validating volume-delay relationships used in the postprocessor.
[51] Description and validation of the Version 2.1/TP/MOBILE6 Emissions Post-Processor, page 9, Memo R. Milone to file.



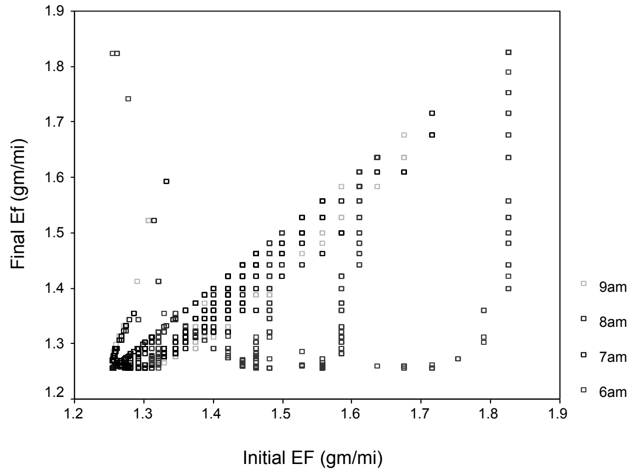


Figure 2a. NOx composite freeway stabilized emission rates for Alexandria.

Figure 2b. Emission rates assigned by speed before (*initial)* and after (*final)* postprocessing.

Figure 2b shows the initial and final running emission rates (i.e., assigned by speed) estimated for the freeway/expressway links. The initial emission rates that would have been assigned had there been no smoothing after assigning 24-hour volumes to an hourly profile are generally lower than final rates based on postprocessed speeds, because the reduced speeds after postprocessing fall into the speed range where the emissions rate is increasing with speed (Figure 2a). Thus, while TPB's postprocessing procedure estimates speed conservatively, the overall effect could be to reduce emissions estimates. Many of the links on which peak spreading occurs are not in the City of Alexandria and consequently might have a different profile of composite running stabilized emission rates, but we would not expect the overall pattern to be markedly different.

Committee members note that while over-capacity links amount to a small fraction of the network and regional VMT, they are presumably concentrated in locations with higher congestion trends. TPB materials indicate that "Traffic assignments on rare occasions produce severely overloaded link volumes to the point where a given link volume could exceed the capacity over *all* hours of the day." It is because of this possibility that volumes in hours 1, 13, and 24 are not spread. Statistics TPB prepared at the committee's request indicate that for the 2005 simulation the spreading has effect on about 25 percent of network links with assigned volume (4,713 links of 18,188 in the road network).[52] TPB analysis indicates that regional overflow VMT during hours 1, 13, and 24 totals 660,197 vehicle-miles, about 0.40 percent of regional total daily VMT.

[52] Peak spreading on some 61 percent (2,886 links of 4,713) did not extend beyond three hours on either side of the peak hour. Estimated volume exceeds 24-hour capacity on fewer than 25 percent of the links on which spreading occurs (1,137 of the 4,713 over-capacity links, about 6 percent of all network links).

An argument may then be made that the impact of peak spreading on high-volume links is likely to be small, but as the committee's analyses illustrate, the nature of that impact is uncertain. The committee agrees that running emissions rates applied by MOBILE6 may be raised or lowered by the speed changes accompanying TPB's postprocessing procedure for estimating hourly volumes. The influence of the procedure on emissions estimates cannot be predicted without rigorous sensitivity testing.

Estimating Emissions Rates

TPB estimates running, hot and cold start, and evaporative emissions rates from MOBILE6 in five composite emissions groups:

- Arterial stabilized running rates by speed, in 1-mph increments;
- Freeway stabilized running rates by speed, in 1-mph increments;
- Freeway ramp rates based on stabilized running at an average 34.6 mph speed, and added vehicle-related hot soak, diurnal, and resting loss components;
- Stabilized local-road running (uniform speed) and vehicle-related rates; and
- Cold and hot start-up rates per trip.

The respective emissions rates are applied to trips and VMT to estimate total regional emissions. The committee observes that TPB relies substantially on MOBILE6 defaults in estimating these emissions rates and thereby follows practices used by other similarly situated MPOs, but the extra effort to weight rates by appropriate activity measures is commendable.

Concluding Observations

The committee has reviewed the state of the practice of TPB's travel demand modeling to assess the performance of the agency's latest travel model and the proposed process for merging the latest travel model outputs to produce mobile source emissions. Our assessment has been based on the idea that travel models may be said to perform well if, in their structure and application, they comprise a plausible explanation of the region's travel patterns and produce simulations of future regional travel that reflect logical responses of those patterns to changes in configuration of the transportation system and operating policies. We have found certain of TPB's practices commendable in the context of practices followed by many MPOs and certain others to be less satisfactory, as discussed in the preceding sections and summarized in our opening paragraphs.

We note that that the work of modeling in the metropolitan Washington area must be carried out in an environment characterized by rapid growth and growing congestion, a knowledgeable and politically active population, and the sometimes competing interests of three states and some 20 local governments comprising the TPB's constituency. Such characteristics, while not necessarily unique to this region, pose difficult challenges, and committee members were pleased with TPB's openness in discussing their travel modeling practices.

We note also that the pressures of annual updating of regional plans and programs are substantial. Perhaps in response to the influence such pressures may exert, TPB's practices tend to convey a management perspective focused sharply on production of results, responsive to the expectations of constituent governments, and sparing with regard to time spent reexamining assumptions and modeling techniques and measuring models' sensitivity to key parameters.

As specified in the study's Statement of Task, we will be preparing a second letter to consider TPB's proposed direction of future model upgrades, travel survey and other data needed to support future model upgrades, and appropriate geographic detail that should be developed for future upgrades. We anticipate making recommendations in that letter for how the performance of TPB's models may be improved.

We appreciate this opportunity to assist TPB in dealing with the complex and sometimes controversial issues of travel demand modeling and its role as a component of mandated regional air quality conformity determinations. We look forward to continuing discussions of these matters.

Yours very truly,

David J. Forkenbrock
Chair

Attachments

Attachment 1. Committee Roster

Chairman:

David J. Forkenbrock
Director and Professor
University of Iowa
Public Policy Center
Iowa City, IA

Members:

Chandra R. Bhat
Associate Professor
University of Texas
Dept. of Civil Engineering
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William A. Davidson
Principal Consultant
PBConsult
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Ronald William Eash
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Evanston, IL

Keith L. Killough
Principal
KLK Consulting
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Debbie A. Niemeier
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University of California
Civil and Environmental Engineering
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Mark L. Schlappi
Systems Analysis Program Manager
Maricopa Association of Governments
Phoenix, AZ

Staff:

Jon Williams
Manager, Synthesis Studies
Transportation Research Board
Washington, DC

Andrew C. Lemer
The Matrix Group, LLC
Baltimore, MD

Attachment 2. Statement of Task

This project will perform review of the state of the practice of travel demand modeling by the Transportation Planning Board (TPB) of the Metropolitan Washington Council of Governments. The review panel will provide guidance on:

1. The performance of the TPB's latest travel model (version 2) in forecasting regional travel;
2. The proposed process for merging the latest travel model outputs to produce mobile source emissions;
3. The TPB's proposed direction of future travel demand model upgrades;
4. Travel survey and other data needed to accomplish future model upgrades; and
5. The detail (grain) of travel analysis zones that should be developed for future upgrades.

Sponsors: Metropolitan Washington Council of Governments

Attachment 3. Public Documents Reviewed by the Committee

Metropolitan Washington Council of Governments. COG/TPB Travel Forecasting Model Version 2.1/TP+, Release C Calibration Report. December 23, 2002.

Metropolitan Washington Council of Governments. Responses to A Critique of the Travel Demand and Air Emission Models of the National Capital Region Transportation Planning Board. June 13, 2002.

Metropolitan Washington Council of Governments. Responses to A Critique of the TPB Version 2 Travel Model and Mobile Source Emissions Estimation Procedures: A Compendium of Comments, Responses, and Related Documents. February 24, 2003.

Metropolitan Washington Council of Governments. Description of the COG/TPB Emissions Post-Processor. February 20, 2003 (unpublished paper).

Federal Highway Administration. "Section D, Specific Regional Analysis Requirements: Chapter 6, Serious and Above Ozone and CO Non-Attainment Areas." In Transportation Conformity Reference Guide. July 31, 2001.

U.S. Environmental Protection Agency. "VIII. Deadline for Use of Network Models and Affected Areas and IX. Content of Network Modeling Requirements in Serious and Above Ozone and CO Areas." 62FR158, 43790-43795. *Federal Register.* August 15, 1997.

Metropolitan Washington Council of Governments. Air Quality Conformity Determination of the 2002 Constrained Long Range Plan the 2003–2008 Transportation Improvement Program for the Washington Metropolitan Region. Draft, July 2002.

Wamsley, J., Sierra Club. Memo to TPB Chairman Mendelson. November 20, 2002.

Forkenbrock, David. *Letter to Dr. Ronald F. Kirby*. March 6, 2003.

Kirby, Ronald F. *Letter to Dr. David Forkenbrock*. March 21, 2003.

Metropolitan Washington Council of Governments. National Capital Region Transportation Planning Board (TPB) and Metropolitan Washington Air Quality Committee (MWAQC) Committee and Subcommittee Structures and Stakeholder Consultation Processes. March 21, 2003.

Metropolitan Washington Council of Governments. Description of Models Development Activities Following 1995 Peer Review. March 21, 2003.

Metropolitan Washington Council of Governments. Representation of Trucks and Other Heavy-Duty Vehicles in Overall Mix of Vehicle Miles of Travel (VMT). March 21, 2003.

Metropolitan Washington Council of Governments. Description and Validation of the Version 2.1/TP+/MOBILE6 Emissions Post-Processor. March 21, 2003.

Metropolitan Washington Council of Governments. FY2003 Unified Planning Work Program (UPWP) for Transportation Planning for the National Capital Region. March 20, 2002.

Ronald F. Kirby. *Letter to Dr. David Forkenbrock*. March 26, 2003.

Metropolitan Washington Council of Governments. Detailed Descriptions and Examples for Specific Aspects of the TPB Travel Model and Emissions Post-Processor. March 26, 2003.

17 a) 1994 Zonal Employment Density Map
17 b) 1994 Zonal Population Density Map
17 c) 1994 Zonal Household Density Map
17 d) 1994 COG/TPB Highway Network and Zone System (1 of 2)
17 e) 1994 COG/TPB Highway Network and Zone System (2 o0f 2)

Forkenbrock, David. *Letter to Dr. Ronald F. Kirby*. April 7, 2003.

Kirby, Ronald F. *Letter to Dr. David Forkenbrock*. April 9, 2003

Metropolitan Washington Council of Governments. Responses to Questions Regarding the COG/TPB Travel Model and Mobile Emissions Estimation Procedures. April 9, 2003.

Metropolitan Washington Council of Governments. Documentation Describing Efforts to Make Specific Modeling Improvements Following 1995 Peer Review. April 9, 2003.

Forkenbrock, David. *Letter to Dr. Ronald F. Kirby*. April 16, 2003.

Kirby, Ronald F. *Letter to Dr. David Forkenbrock*. April 17, 2003.

Metropolitan Washington Council of Governments. Response to Additional Questions Regarding COG/TPB Travel Modeling and Mobile Emissions Estimation Procedures. April 17, 2003.

Attachment 4. Agendas and Participants in Committee Meetings and Teleconferences

1st Meeting: February 27–28, 2003; Washington, D.C.

Participants:

Committee members	Guests (Thur. only)	TRB staff, consultant
D. Forkenbrock	M. Clifford, TPB	H. Berlin (Thur. only)
C. Bhat	R. Griffiths, TPB	S. Godwin (Thur. only)
W. Davidson	J. Hogan, TPB	A. Lemer
R. Eash	R. Kirby, TPB	J. Williams
K. Killough	R. Milone, TPB	
D. Niemeier	S. Adidani, Va. DOT	
M. Schlappi	R. Chase, Northern Virginia Transportation Alliance	
	K. Coddington, Greater Washington Board of Trade	
	R. Grow, Greater Washington Board of Trade	
	E. Graye, Maryland-National Capitol Park and Planning Commission (Montgomery County)	
	B. Mann, Virginia Dept. of Transportation	
	P. Mendelson, D.C. City Council	
	M. Replogle, Environmental Defense	

Thursday, February 27

9 am - 10:30 am	Closed session
10:30 am - 1:45 pm	Presentations by TPB staff; questions and discussion
1:45 pm - 2:45 pm	Presentation by M. Replogle, Environmental Defense; questions and discussion
2:45 pm - 3:30 pm	Presentations or statements by R. Chase, R. Grow, E. Graye, B. Mann, P. Mendelson; questions and discussion
3:30 pm - 5:00 pm	Committee questions and discussion with guests
5:00 pm - 5:30 pm	Break
5:30 pm - 6:30 pm	Reception for committee, invited guests, and TRB staff
6:30 pm - 8:30 pm	Working dinner for committee members and TRB staff

Friday, February 28 -- Room 202

8:30 am - 3:00 pm	Closed session

Teleconference: March 31, 2003

Participants:

Committee members	Guests	TRB staff, consultant
D. Forkenbrock	M. Clifford, TPB	S. Godwin
C. Bhat	R. Griffiths, TPB	A. Lemer
R. Eash	R. Kirby, TPB	J. Williams
K. Killough	R. Milone, TPB	
D. Niemeier		
M. Schlappi		

12:00 noon - 1:00 pm	Closed session
1:00 pm - 2:30 pm	Discussion of committee questions and requests for additional information

2nd Meeting: April 11, 2003, Denver, Colorado

Participants:

Committee members	Guests (via teleconference)	TRB staff, consultant
D. Forkenbrock	M. Clifford, TPB	S. Godwin (via teleconference)
C. Bhat	J. Hogan, TPB	A. Lemer
W. Davidson	R. Kirby, TPB	J. Williams
R. Eash	R. Milone, TPB	
K. Killough		
D. Niemeier (via teleconference)		
M. Schlappi		

8:30 am - 12:30 pm	Closed session
8:30 am - 11:30 am	Discussion of issues to be addressed in first letter report, information in hand, tone, structure, and content of draft
11:30 am - 12:00 noon	Plan for teleconference with COG ▪ clarification of matters related to information received ▪ questions raised by committee discussions
12:00 noon -12:30 pm	Break
12:30 pm - 2:30 pm	Open session: Discussion by teleconference with COG staff and others regarding information provided in response to committee requests and other questions that may arise
2:30 pm - 8:00 pm	Closed Session

2:30 pm - 3:00 pm	Review of teleconference results, identification of points requiring clarification by COG staff, if any
3:00 pm - 4:30 pm	Discussion leading to agreement on committee's findings and recommendations to be presented in Letter Report 1
4:30 pm - 5:00 pm	Plans and schedule for completion of Letter Report 1 and balance of study, future meetings, and teleconferences

Teleconference: April 28, 2003

Participants:

Committee members	TRB staff, consultant
C. Bhat	A. Lemer
W. Davidson	J. Williams
R. Eash	
K. Killough	
D. Niemeier	
M. Schlappi	

12:00 noon - 1:00 pm	Discussion of committee observations, questions and requests for additional information (closed session)

Attachment 5. Letter 1 Table of Contents