CHAPTER 2

KEY TRANSPORTATION VARIABLES REQUIRED FOR AIR QUALITY MODELING

INTRODUCTION

This chapter discusses the implications of this legislation in terms of the variables required for air quality modeling. Increasingly, air quality concerns are dictating the information required from the transportation planning process; however, the regional travel forecasting system in use today was not designed specifically to provide the information needed for air quality models. The conformity regulations have addressed this issue by setting priorities for improvements and modifications to specific aspects of the travel forecasting process as they relate to the needs of air quality planning.

Goals

The goals of this chapter are as follows:

- To document the air quality modeling procedures currently used;
- To identify the most important variables needed for air quality analysis;
- To develop a structured matrix for the data requirements that will specify
  — The data type,
  — A general description of the exact data required,
  — The geographic detail required,
  — The use of each data item in air quality planning,
  — What current practices are used to develop the data,
  — What sources of data are available, and
  — What the level of accuracy is;
- To review the problems surrounding each of the data items identified; and
- To identify variables not currently available from the transportation planning process.

While recognizing that several different air quality models are available, this study addresses only the needs of the EPA MOBILE5a model. New models that may be used in the future (e.g., modal-emissions models) and their requirements are beyond the scope of this study.

Background to the Variables Required for Air Quality Analyses

Figure 2-1 identifies the components that will ultimately determine what procedures and variables are required in order to conduct air quality analyses in an area.

The CAAA and the 1993 Conformity Rule

The CAAA provided the impetus for many federal and local initiatives to improve ambient air quality standards. The amendments also required actions, including the development of methods to improve how mobile source emissions are determined and forecast.

In many ways, the 1993 Conformity Rule determines the importance and the types of transportation variables that will be required. The Rule emphasizes consideration of the following:

- How to improve the travel forecasting models and procedures,
- How assumed scenarios of land development and future transportation systems will interact, and
- How to identify and measure travel demand.

Level of Nonattainment by Pollutant Type

Table 2-1 shows the CAAA classifications for areas, on the basis of their level of nonattainment by pollutant type. This classification scheme mandated deadlines for attaining the NAAQS and determined the actions required by areas in conducting air quality analysis and undertaking project conformity analysis.

Actions Required for Air Quality Analyses

Air quality analyses are generally conducted at either the mesoscale or microscale level. Mesoscale analyses are used to calculate the total emissions generated by mobile sources for the region. They are also used to predict emissions from proposed programs and projects as well as from the surround-
Ozone Monitoring

Marginal Areas (>0.121 ppm)

Areas with marginal ozone levels were required to develop a base-year inventory to establish the relative mobile source contribution to overall pollution problems. This inventory was required to incorporate the following elements:

1. The definition of a road network for a given year.
2. The subdivision of this network into traffic analysis zones (TAZs).
3. Forecasting of trips using a transportation-demand model.
4. Assignment of these trips to the network.
5. Validation of the model results against traffic counts and known capacities.
6. Determination of VMT and average speeds by functional class of roadway.
7. The development of emission factors using an emission factor model, and
8. Calculation of total daily vehicle emissions.

The inventory should reflect emissions during the summer, because the EPA deems this period critical in the formation of photochemical oxidants. Emissions should also have been calculated for a “target year” and an attainment year. These estimates must be reviewed and analyzed regularly.

Moderate Areas (>0.138 ppm)

Added to the above requirements are

9. Demonstration of a 15 percent VOC reduction between 1990 and 1996 and
10. Adoption of a basic I/M program.

Serious Areas (>0.160 ppm)

Added to the above requirements are

11. A 15 percent VOC reduction by 1996 and a 3 percent annual average reduction every 3 years thereafter until attainment is reached;
12. Regular monitoring of VMT, vehicle emissions, and congestion;
13. Clean-fuel vehicle programs to be included in SIP revisions; and
14. Adoption of enhanced I/M programs.

Severe 1 and Above (>0.180 ppm)

Added to the above requirements are

15. Offsetting growth in emissions resulting from VMT and vehicle trip growth:

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Classification</th>
<th>Marginal</th>
<th>Moderate</th>
<th>Serious</th>
<th>Moderate</th>
<th>Serious</th>
<th>Serious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td></td>
<td>0.121 up to 0.138</td>
<td>0.138 up to 0.160</td>
<td>0.160 up to 0.180</td>
<td>0.180 up to 0.190</td>
<td>0.190 up to 0.280</td>
<td>0.280 and above</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td></td>
<td>9.1 up to 12.7</td>
<td>12.8 up to 16.4</td>
<td>16.5 and above</td>
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</tbody>
</table>

Figure 2-1. Factors determining the variables required.
16. Employer trip reduction programs for all employers with more than 100 employees; and
17. In areas where ozone is greater than 0.280 ppm, any SIP revision may restrict high-polluting or heavy-duty goods vehicles during peak hours.

**Carbon Monoxide Monitoring**

**Moderate 1 Areas (>9.1 ppm)**

Areas with such CO levels were required to develop a base-year emissions inventory incorporating the following elements:

1. Emissions that reflected a typical operating day during the peak CO season for that area (generally, the winter);
2. CO emissions by county, vehicle class, and roadway type; and
3. Mobile emissions from local and arterial traffic.

Periodic inventories were also required for future years, encompassing the same elements as the base-year inventory.

**Moderate 2 Areas (>127 ppm)**

Added to the above requirements are

4. Comprehensive emission inventories from all CO sources, to be updated every 3 years;
5. Annual VMT forecasts up to the year of attainment;
6. Reports on the accuracy of the forecasts;
7. Adoption of I/M programs; and
8. Any gasoline sold in the metropolitan statistical area (MSA) or consolidated MSA (CMSA) must contain less than 2.7 percent oxygen by weight. This requirement must be in effect for not less than 4 months per year.

These areas were also required to develop modeling inventories for the base year and for future years in order to determine if proposed SIP control strategies would be adequate to reach attainment by the designated date. These inventories should be developed from areawide and hot-spot modeling done using an EPA-approved dispersion model.

**Serious Areas (>16.5 ppm)**

In addition to the preceding requirements, areas with serious CO levels must undertake the following actions:

9. VMT tracking, forecasting, and comparisons and 10. Specific measures to offset VMT and vehicle trips.

**PM-10 Monitoring**

**Moderate Areas**

Areas deemed moderate in nonattainment of PM-10 standards were required to submit a SIP by November 15, 1991. This SIP was to include the following elements:

1. Demonstration that attainment would be reached on or before December 31, 1994, or a demonstration that attainment by that date would be impractical; and
2. Provisions to ensure that reasonably available control measures (RACM) for the control of PM-10 would be implemented by December 10, 1993.

**Serious Areas**

Areas that the EPA determines cannot or have failed to practically attain the NAAQS for PM-10 will be reclassified as Serious. These areas have until December 31, 2001, to reach attainment.

**The 1993 Conformity Rule**

The Conformity Rule requires that all proposed regionally significant transportation projects (irrespective of funding source) must be modeled and VMT must be estimated in accordance with "reasonable professional practice." Areas rated as Serious, Severe, and Extreme ozone nonattainment areas and Serious carbon-monoxide nonattainment areas after January 1, 1995, must estimate their regional transportation-related emissions, which are used to support conformity decisions, according to the following procedures:

1. Develop network-based transportation models to estimate travel within the metropolitan planning area of the nonattainment area. The models must have the following attributes:
   • The transportation model must be validated through ground counts, conducted less than 10 years before conformity determination.
   • Capacity-sensitive assignment methodology must be used for peak-period traffic assignments.
   • Zone-to-zone travel times that are used to distribute trips between origin-destination pairs are to be compared with the travel times following the assignment procedure (these times should also be used to model mode choice).
   • Peak and off-peak travel demand and travel times must be used.
   • If the necessary information is available, sensitivity to pricing must be incorporated when modeling trip distribution and mode choice.
• There must be a logical correspondence between the assumed scenario of land development and use and the future transportation system for which emissions are being estimated.
• The effect that the transportation system itself has on trip generation or the decisions to travel must be modeled.

2. Calibrate the estimates of VMT from the models, with estimates obtained from HPMS procedures, to develop a factor (or factors) that can then be applied to the model estimates of future-year VMT.

3. Estimate nonattainment-area vehicle travel on off-network roadways within the urban transportation-planning area and on roadways outside this area.

4. Speeds and delays are to be estimated in a way sensitive to the estimated volume of travel on each link in the network.

In addition to these requirements, transportation plans adopted in these areas, after January 1, 1995 must contain the following information:

5. The demographic and employment factors influencing expected transportation demand, including land-use forecasts, must be provided.

6. Additions to the highway network must be modeled under different volumes of traffic.

7. The way in which the transit system is expected to develop must be described so that future transit ridership can be modeled.

• Determine the level of spatial and temporal resolution required (for dispersion models, information must be provided on an hourly, gridded basis);
• Determine total base-year VMT by functional class of roadway;
• Develop growth factors and predict future-year VMT;
• Develop emission factors on the basis of the rates at which different pollutants are emitted per VMT by various types of vehicles in various operating modes;
• Multiply these emission factors by calculated VMT to determine total mobile source emissions for the nonattainment region;
• Determine emissions from area sources and point sources to calculate total emissions for the nonattainment region;
• Provide meteorological, boundary, and terrain data that, with total emissions, are required as inputs for the dispersion models; and
• Determine ambient pollutant concentrations.

The accuracy of the final emissions estimates is linked strongly to the methodologies and algorithms employed by the emissions models and the accuracy of the data obtained from the transportation and emissions-factor models. These models, in turn, depend on accurate data and employ certain methodologies. Error could be propagated from the start of the modeling procedure through to the final estimates.

Site-Specific Requirements

There are also site-specific requirements, relating to CO and PM-10 emissions. These requirements will affect the level of detailed analysis needed to ensure conformity in the following cases:

• Projects in locations that are current or possible sites of violation;
• Projects affecting the worst three intersections in the urban area (i.e., those intersections with the highest volumes of traffic in the urban area); and
• Projects affecting the worst three intersections in terms of Level of Service (LOS) (these intersections do not necessarily also have the highest volumes of traffic).

The Models and Procedures Employed

The classification of an area and the subsequent actions that the area is required to carry out will determine the models and procedures it should employ. The broad processes that should be followed to develop pollution estimates are as follows:

ESTIMATING MOBILE SOURCE EMISSIONS

Ozone Nonattainment Areas

Background

The formation of ozone and its health implications were discussed in Chapter 1. These facts about the formation and transport of ozone mean that areas in nonattainment for ozone must perform a mesoscale analysis encompassing the whole region. Base- and future-year inventories must be developed for mobile source emissions of HC and NOx in the nonattainment region using an EPA-approved emissions-factor model. This involves MOBILE5a for all areas except California, which uses the EMFAC7F model developed by the California Air Resources Board (CARB).

Estimating Mobile Source Emissions of Ozone Precursors

Figure 2-2 presents an overview of the procedures required to develop estimates of HC and NOx. Basically, VMT multiplied by emission factor produces estimates of emissions. However, the level of detail for these values must be compatible with the scope of analysis and EPA require-
Figure 2-2. Process of mobile source emissions estimation.

- Determining the level of detail required,
- Calculating the emission factors, and
- Estimating base- and future-year VMT.

**Level of Detail Required**

Conformity rules require that HC and NOx emissions be calculated on an average daily basis. These rates should be adjusted to reflect travel during the summer. Nonattainment areas rated as Serious and higher are also required to calculate emissions for specific times in the day. Nonattainment areas also may be required to model how the pollutants disperse and mix under given atmospheric conditions, so as to develop ambient concentrations for the whole region. For this purpose, a regional dispersion model would be used.

**Calculating Emission Factors and Rates**

Emission rate models, such as MOBILE5a and EMFAC7F, provide estimates of the rates at which different pollutants are emitted in grams per mile of vehicle travel by various types of vehicles. The models incorporate an extensive database of measured emission rates (e.g., MOBILE5a uses measured emission rates from a sample of vehicles run through the Federal Test Procedure [FTP]) and procedures for adapting these rates to actual on-road operating conditions.

The on-road operating conditions include whether the vehicle is in the cold/hot-transient or the hot-stabilized operating mode, the average speed at which the vehicle is moving, what the environmental conditions are, and whether any I/M program is planned or in place in the area.

Emission-factor models also incorporate information on the age distribution and use for each vehicle type.

**Estimating Base- and Future Year VMT**

The CAAA and the Conformity Rule state that HPMS estimates of VMT should be the primary means by which total travel is calculated in the nonattainment area. These estimates have been calculated for various functional classes of roadways, using FHWA-approved statistical and sampling
procedures. (This will be discussed in greater detail in the subsection on VMT.)

Total VMT is estimated for the region in the base year of analysis using the output of travel demand models or HPMS data. When using HPMS data, growth rates are derived from these figures and historical trend data. These growth rates are applied to determine future-year VMT. When using travel demand models, the socioeconomic inputs are predicted for the future year to estimate future VMT. These calculations of VMT can then be multiplied by the emissions factors to derive the total vehicle emissions for the region.

Regional Dispersion Models—The Urban Airshed Model

Ozone formation is predicted using photochemical dispersion models that use mobile source emissions as inputs. The most widely used regional dispersion model is the UAM. This model incorporates a three-dimensional (3-D) photochemical grid to simulate the atmosphere. Its purpose is to calculate concentrations of pollutants by simulating physical and chemical processes in the atmosphere that affect pollutant concentrations. The UAM uses atmospheric diffusion or species continuity equations that represent a mass balance in which all of the relevant emissions, transport, diffusion, chemical reactions, and removal processes are expressed mathematically. The UAM’s applications include the following:

- Calculation of summer ozone and winter CO levels and
- Projection of hourly patterns on the basis of future emissions scenarios.

For urban applications, the model is usually used to simulate a 2- or 3-day ozone episode. The data requirements for this are as follows:

- Hourly estimates of the height of the mixed layer, which requires day-specific upper air temperatures and wind data at various times;
- A 3-D wind-field for each hour;
- Ambient temperature, humidity, atmospheric pressure, solar radiation, cloud cover, and the chemical species to be simulated; and
- Hourly gridded emissions for NO, and VOCs. (VOCs must be classified by carbon-based class because the UAM employs carbon-based chemical kinetic mechanisms.)

Some typical outputs of the UAM include the following:

- Average concentrations by hour and grid square for all species and
- Instantaneous concentrations for each species by grid square at the beginning of the averaging period.

Carbon Monoxide Nonattainment Areas

Background

As discussed in Chapter 1, areas in nonattainment for CO must perform microscale analyses that concentrate on the point of emission.

Determining Mobile Source Emissions of Carbon Monoxide

Receptors are used to measure the point-source emissions and provide information for a specific site such as an intersection. To estimate CO emissions, the following traffic data parameters are required:

- Peak-hour/design-hour traffic volumes;
- Roadway capacities for each approach;
- Roadway characteristics, such as number of lanes and segment length;
- Free-flow speeds;
- Turning movements;
- Truck and bus percentages;
- Traffic-control information, such as phasing, cycle length, and green/cycle-time ratio;
- Vehicle-age distribution;
- Vehicle-type classification;
- Percent hot/cold starts; and
- Distance from the receptors to the road.

Network characteristics and traffic operating conditions directly affect emission levels at a site. Several microscale simulation models aim to replicate the movement of vehicles through a section of the network under various scenarios. Output statistics are produced relating to the operational performance of the system under given conditions. This includes calculating the vehicle emissions of HC, NO, and CO.

Figure 2-3 shows the inputs and outputs for microscale travel simulation models in the context of emissions modeling. The critical parameter is to determine the mode of operation of the vehicle during the time it is on the analysis link. This relates to the proportion of time it is at free-flow speed in the acceleration and deceleration modes, and idling, and the delay it experiences. These times are averaged over the stream to produce average rates (usually per hour).

Calculating Emission Factors

The accuracy of the emission estimates of traffic simulation models is in doubt. For the purposes of conformity decisions, the EPA requires emission factors to be developed using an approved emissions-factor model. These factors are then adjusted to reflect the different emission rates experienced in each of the operating modes. For example, emission rates are higher when a vehicle is idling or accelerating.
Dispersion Modeling

CO emissions are usually generated during peak-hours and are measured in grams per vehicle-mile for use in dispersion models. These models use meteorological, transportation, emission, and other site-specific information to predict concentrations of pollutants downwind from the modeled source.

To model the dispersion of CO, models of the Gaussian line-source type are most widely used. If one considers a single isolated point source, such as the smoke stack of a power plant, the plume rises because it is warmer than the surrounding air. As the plume is advected downwind, it is subjected to atmospheric turbulence that causes it to diffuse from the source; therefore, pollutant concentrations decrease with increasing distance from the center line of the plume.

The spreading and wafting of plumes will be influenced by wind speed, direction, and various other dispersion parameters. As wind speed increases, the distance between the particles within the plume will increase. The net effect is that pollutant concentrations are generally inversely proportional to wind speed.

The stability and mixing height will also influence the dispersion of the plume. If there is a high degree of atmospheric turbulence, this will tend to spread the plume more rapidly. If the plume has spread vertically so that the upper margin of the plume is contained by an inversion, the mixing height is reduced. This increases the concentration of the pollutant between the ground and the base of the inversion layer.

The height of the emission source also affects ground-level concentrations. The greater the height of the emission, the further the plume will have to spread, before significant concentrations are observed at the ground level.

These factors are the principles behind Gaussian plume models, such as CAL3QHC and CALINE-4, used in mobile-source-related analyses. These models calculate how pollutants are dispersed by representing the relationships discussed in the form of mathematical equations.

CAL3QHC is the EPA-required dispersion model to be used in hot-spot analyses in all areas, except California, which has recently developed the CALINE-4 model. (Both models supersede CALINE-3, which was typically used for modeling free-flow roadway conditions.) Figure 2-4 shows the data requirements and processes involved in modeling CO emissions concentration.

CAL3QHC is generally used for modeling emissions at intersections, although it can be used to model free-flow conditions as well. To run CAL3QHC, the following inputs are required hourly:

- Wind speed in meters per second,
- Wind angle with respect to the positive Y-axis in degrees.
- Atmospheric-stability measure—a numeric value to account for the effect of atmospheric turbulence on the dispersion process,
- Mixing height and width in meters,
- Receptor information (e.g., number, height, angle of observation, and distance from the road),
- Roadway characteristics (e.g., number of lanes and segment length),
- Section type (e.g., at grade, fill, bridge, and depressed),
- Coordinates of the endpoints of the link,
- Signal cycle in use,
- Free-flow and idle emission factors (obtained from the MOBILE models),
- Traffic volumes in vehicles per hour and averaged for an 8-hr period,
- Background concentrations of the specific pollutant, and
- Height of the pollutant source.

CALQHC works by considering the intersection as a series of links on which vehicles are in different modes of operation. The model takes the input data and calculates the average queue lengths over the specified time. Different emission factors from the MOBILE5a model are then applied, on the basis of whether the vehicle is idling (queued) or in free flow. Output is the concentration of the pollutant in parts per million. CO estimates are produced for both 1- and 8-hr periods during the peak CO season, generally the winter.

**PM-10 Nonattainment Areas**

**Definition**

PM-10, which is a product of combustion, machinery and tire wear, and facility/road condition, affects the aesthetic environment and is a health hazard if breathed in large doses.

**Estimating PM-10 Levels**

The general methodology for modeling PM-10 levels is similar to that adopted for CO modeling. Emissions are recorded at the site of study to get a peak-hour value. This is then input into a dispersion model, along with atmospheric and traffic characteristics, to obtain the concentration of the pollutant in parts per million.

PART5 is the EPA-approved model that should be used to calculate fugitive dust emission factors. It calculates particle
emission factors in grams per mile from on-road automobiles, trucks, and motorcycles, for particle sizes up to 10 microns. The particulate emission factors include exhaust particulate, exhaust particulate components, brake wear, tire wear, and reentrained dust—all of which are required for PM-10 inventories and analyses. (This model supersedes the use of AP-42 emission factors.) The inputs required for this model are as follows:

- Overall fleet average weight,
- Overall fleet average number of wheels,
- Average vehicle speed,
- Roadway site loading characteristics,
- Atmospheric and meteorological conditions, and
- VMT mix and mileage accumulation rates (optional, can accept default).

KEY TRANSPORTATION VARIABLES REQUIRED FOR AIR QUALITY MODELING

Defining the Transportation Variables Required for Air Quality Modeling

This discussion of the air quality modeling process makes clear that several transportation variables are required as inputs to the emissions models. These variables must be available in a format compatible with the requirements of these models. Frequently, however, data are not available in the desired format. These variables are examined according to the specifications stated in the goals of this section.

Data Type: Average Vehicle Speeds

General Description

Emission factors (grams per mile) vary considerably with vehicle speeds. In general, emission rates are very high at very low speeds for VOCs and CO, with emissions decreasing (sharply at first and then more gradually) with increasing speeds. Emission rates for NOx increase with higher engine temperatures. In general, NOx emission rates also increase with increasing speeds. The minimum VOC and CO emission rates are reached at around 48 mph and the minimum NOx emission rates are reached at around 19 mph. Increases in speed result in increased emissions at speeds above 48 mph for VOCs and CO and above 19 mph for NOx.

Various speed measures are used by transportation and highway engineers for different purposes. Spot speeds represent the instantaneous speed as a vehicle passes a given point on the roadway. Spot speed analyses usually involve the estimation of the time-mean-speed of vehicles passing that point. Running speeds measure the average speed over a section of roadway, while the vehicles are in motion. In this case, analyses usually involve the estimation of the space-mean-speed. Average travel speeds along a route segment represent the overall speed, including delays. MOBILE5a expects average travel speeds for determining emission factors, because this model was calibrated with average speed values of driving cycles used for exhaust emissions tests.

MOBILE5a’s database was developed testing vehicles under different driving cycles, including the FTP. These tests involve measuring exhaust emissions of vehicles traveling under known driving and environmental conditions. During each driving sequence, the vehicle accelerates, decelerates, and idles as in normal urban driving conditions. The average overall speed of the FTP’s driving cycle is 19.6 mph, with a maximum speed of 56.7 mph; 17.6 percent of the test time is spent idling. These base emission rates are then adjusted with speed-correction factors (SCFs) to reflect a range of other average overall speeds.

Average vehicle speeds are affected by the capacity of a roadway and the volume of traffic on that roadway. As the volume and density of the traffic increase, the LOS worsens, and speeds deteriorate. The implications for analysis are that average speeds must be determined for different roadways at different times of the day. The 1993 Conformity Rule identifies the need to estimate speeds and delays in a manner sensitive to the estimated volumes of traffic on each link in the network.

To summarize, the data requirements are for average travel speeds by functional class of roadway and time of day and free-flow link speeds.

Geographic Detail

Speeds are generally developed for the entire area by functional class, or specific subareas and functional class, although speeds may be calculated by link in a few cases.

Use in Air Quality Planning

MOBILE5a requires the average travel speed, which is the speed over a length of roadway, including delays, because MOBILE5a incorporates speed measures on the basis of “typical” driving cycles, including the FTP. Where localized emissions are to be modeled, the average speed is needed by grid location. Because conventional models can produce link speeds on the network, average link speeds can be obtained by manipulation.

Current Practices and Sources of Data

Despite the problems associated with directly using the speeds from the network model as an input to MOBILE5a, this is one of the most common current practices. Typically, planners will develop speed estimates by taking the 24-hr VMT and dividing this by the 24-hr vehicle-hours of travel (VHT). This should be done for each functional class of roadway in order to mitigate some of the effects of aggregation.
Although speeds can be estimated for each link individually, standard planning practice is to use a speed-flow curve, such as the Bureau of Public Roads (BPR) curve, to estimate the speed on a link given the initial free-flow speed and the volume-to-capacity (V/C) ratio. The standard equation for the BPR curve is

\[
\text{congested speed} = \frac{\text{free-flow speed}}{[1 + 0.15V(C)]}
\]

where \( V \) = the assigned volume on the link
\( C \) = the practical capacity of the link

Although the BPR curve, originally derived from a small sample of freeway segments, was intended to apply specifically to freeways and to use capacity defined as the capacity at LOS C, neither the restriction to freeways nor the definition of capacity as being the capacity for LOS C have been observed in the practice of transportation planning for at least 30 years. Rather, standard practice is to apply the BPR curve to all functional classes of roadway and to define practical capacity as capacity under prevailing conditions. Often, this is capacity under LOS E, and sometimes even LOS F. Figure 2-5 shows a comparison of four speed-flow curves developed for freeways. The standard BPR formula does not degrade speeds sufficiently as volume approaches capacity (which it probably was never intended to do, given the noted restrictions). The Highway Capacity Manual curve is based on an eight-lane freeway with a design speed of 70 mph. The Mod.BPR4 curve is the result of changing the coefficient of the V/C ratio from 0.15 to 1, while the Mod.BPR10 curve seeks to correct the underprediction of speeds for V/C above 0.5. The latter curve provides the best fit to the Highway Capacity Manual curve, particularly at higher V/C ratios.

For arterial streets, the situation is more complicated. Chapter 11 of the 1985 Highway Capacity Manual contains a method for determining average speeds on arterials on the basis of free-flow speeds, intersection spacing, signal timing, and functional class. Running speed between intersections is calculated from this information, along with the total delay per intersection. The running speed and total intersection delay are then combined to determine average travel speed for the arterial. Intersection delay can be calculated using the 1985 Highway Capacity Manual formulas in Chapter 11. These equations require assumptions of the effective green time per cycle, the V/C ratios for each lane, and the through-lane capacity.

The HPMS analytical process (HPMS AP) attempts to incorporate measures of the mode of operation, or the "drive cycle" of vehicles, into the computations for average travel speed. It computes average travel speeds in miles per hour for

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**Figure 2-5. Examples of speed-flow curves.**
various vehicle types, classes of roads and geographic areas, and other strata by incorporating in the procedure such factors as speed change and stop cycles, idle time, and pavement and geometric characteristics.

Other methods of calculating speeds include empirical observations using spot speeds, average running speeds, or video surveillance. This will depend on the efforts of the relevant state DOTs. Free-flow speeds should be estimated empirically.

Level of Accuracy

Because emissions rates are sensitive to changes in average speed, speeds must be estimated accurately. However, the regional travel forecasting models from which average speed data are taken were not designed to produce accurate speeds, but to produce accurate volumes. Speeds estimated using these models for congested traffic conditions probably would have a high margin of error, mainly because the BPR formula used as the capacity-restraint function was not designed to function under these conditions.

Typically, a network model will incorporate free-flow speeds reflecting the speed limits of functional classes of roadways; however, evidence suggests that the free-flow speed is higher than the posted speed limit (e.g., Benson, Mullins, and Clark, 1993). Therefore, free-flow and congested speeds must be validated by empirical observations.

The HPMS AP cannot simulate speeds lower than 13 mph, although it uses a methodology more applicable to the requirements of the air quality models. Because CO and hydrocarbon (HC) emissions are proportionally much greater when a vehicle operates under congested conditions and accelerates, it is critical to determine the amount of time that this occurs.

MOBILE5a assumes that the driving cycle values of the FTP and supplemental test cycles are typical for their speeds (i.e., the amount of cruising, acceleration, deceleration, and idling during the tests are presumed to apply to all other driving conditions). This is not the case, because the same value of average travel speed can result from several combinations of the amount of time spent in each driving mode.

In a modeling context, the most accurate way of estimating average travel or route speeds is to use traffic simulation models, such as NETSIM. It is infeasible to simulate every link and intersection in the network to estimate speeds. An alternative may be to develop simplified relationships between vehicle speeds and highway conditions for different times of the day, which can be applied to like conditions in the network.

If the speeds input into the air quality models are overstated, there may be severe under- or overestimates of emissions. There may also be underestimates of the effects of congestion and, consequently, the effect of congestion-relieving strategies. This will also result in underestimation of the margin of difference between mixed-flow and reserved high-occupancy vehicle (HOV) lanes, which will result in a reduction of the potential of this TCM to affect the choice of travel mode. Overstated speeds will also lead to a decrease in the sensitivity of mode choice to travel time differences between auto and transit, unless transit times are calibrated accordingly. This will become more apparent under conditions of congestion, when the true differences in travel times, where transit has its own right of way, actually widen, resulting in an underestimation of shifts to transit.

There is a recognition of the need to take the final assignment of volumes and recalculate speeds, so that they represent the observed speeds on the highway more accurately. Several studies have addressed this issue of "post-processing" the output of the network travel demand models (e.g., Walker 1992; Benson, Mullins, and Clark, 1993). The primary problem is obtaining up-to-date speed data, particularly if information is required at the grid level. One possibility is to calibrate the output speeds with speeds that reflect census journey-to-work data. This should assist in providing more accurate predictions of average speeds under congested conditions.

The output from a travel forecasting model gives a value for the average speed on a given link. In reality, these speeds will vary by time and even by lane. An area being researched in California by the CARB is concentrating on the "path" of the vehicle or how it got to that speed. The CARB defines "path" as the mix of acceleration, deceleration, and steady speeds involved in the vehicle operation and subsumed in an average speed. The study consisted of equipping vehicles with "event" computers that capture key-on to key-off measurements of speed, distance, temperature, and trips. This "Netson Family" of drivers has already provided information on trip generation that differs from previous assumptions derived from driver surveys and may be of use to redefine the transportation models.

Another area receiving much attention is the use of global positioning system (GPS) techniques. GPS involves the use of wireless communication to pinpoint where a vehicle is on the network at any moment in time. From this, it is possible to determine link-by-link speeds on the path of the vehicle.

Data Type: VMT

General Description

VMT is a principal requirement for forecasts of mobile source emissions. Total national VMT has been increasing continuously because of

- Increasing vehicle ownership,
- An increase in the number of workers,
- Longer average trip lengths,
- Growth in suburban to suburban travel,
- A decrease in average auto occupancy, and
- Continued decreases in the real costs of driving.
Nonattainment areas must provide base-year VMT and forecasts of future VMT, by vehicle mix and functional class of roadway. For ozone and CO nonattainment areas rated Serious and higher, the CAAA requires VMT tracking, forecasting, and comparisons. CO nonattainment areas rated Moderate and higher must provide annual VMT forecasts until attainment is reached. Where photochemical dispersion modeling is required, VMT must be provided by hour of the day and by grid square.

To summarize, the VMT-related data commonly needed are

- VMT for the entire nonattainment area whose areas are rated Serious and higher for CO and ozone;
- VMT by functional class of roadway;
- The percentage of VMT accumulated by each vehicle class for each functional class of roadway;
- Seasonal variations in VMT;
- Year-by-year VMT forecasting, tracking, and comparisons for areas rated as Serious and higher for nonattainment of CO;
- Estimates of VMT on off-network roadways within the urban transportation planning area and roadways outside the planning area; and
- VMT by grid square and hour of the day for photochemical dispersion modeling (e.g., the UAM).

Geographic Detail

The level of geographic detail depends on the type of modeling required as follows

- To perform regional travel modeling, data on the functional classes of roadway are necessary and
- To perform photochemical dispersion modeling, a grid system is analyzed.

Uses in Air Quality Planning

The uses of VMT in air quality planning are primarily as follows:

- VMT is required by functional class for the whole subregion so that these values can be multiplied by emissions factors to estimate total vehicle emissions; and
- Photochemical dispersion models require VMT to be stratified by hour of the day and by grid square, to assess the hourly emissions within the UAM grids.

Current Practices and Sources of Data: HPMS and Network Models

Two approaches to VMT estimation are acceptable to the EPA for areawide emissions estimation. These are HPMS and network-based travel demand models (Harvey and Deakin, 1992). In this subsection, HPMS is examined in detail; network modeling is examined briefly. (A detailed analysis of network modeling is presented in Chapter 7.)

HPMS was developed by FHWA in the mid-1970s to monitor and assess the status and needs of the nation's highways. The HPMS universe consists of all public highways or roads within a state. These are classified by functional class and area type (urban and rural). In rural areas, the functional classes are interstate, other principal arterial, minor arterial, major collector, minor collector, and local. In urban areas, they are interstate, other freeway or expressway, other principal arterial, minor arterial, collector, and local. A third level of stratification, based on 13 volume groups, was added to the HPMS as a statistical device to reduce sample size, ensure the inclusion of higher volume sections in a sample, and increase the precision of VMT at a lower sample rate.

The HPMS sampling elements are defined on the basis of road segments or links that include both directions of travel and all travel lanes within the segment. Sample size is determined on the basis of the coefficient of variation of traffic volume and desired level of precision for each volume group, and the sample is selected as a simple random sample within different strata. HPMS sampling includes all classes of roads, except rural minor collector, rural local, and urban local. Sampling and the expansion of samples are done for each nonattainment area.

Typically, an agency will take 24- or 48-hr traffic counts on each sample segment once every 2 years. These counts are then adjusted, on the basis of day-of-week and season, to annual averages on the basis of data from a few continuous traffic recorders. The HPMS expansion factors are computed as the ratio of universe mileage to sample mileage within each stratum. This procedure expands the HPMS sample to represent the universe of all roadways in the area by multiplying each segment's VMT by an expansion factor and summing the product for each sample stratum. Axle correction factors are incorporated into the process to account for large trucks in traffic.

Once the base-year VMT has been estimated, future VMT must be determined. Typically, this is done by the derivation of growth rates on the basis of trends in VMT in the past. These growth rates can then be applied to forecast VMT for each functional class of roadway for the critical years in the future.

Base- and future-year VMT can also be calculated following the traffic assignment stage of the conventional travel forecasting process, preferably using an equilibrium assignment procedure. VMT can then be determined by multiplying the volume on each link by the link length. Future-year VMT should be determined by projecting forward the variables used in the base-year models. This should also include predictions about the future highway networks that the area envisages for the target, attainment, and horizon years.
The aggregate VMT estimates produced from the transportation planning models must be made consistent with HPMS estimates. Problems associated with doing this include:

- The boundary of the nonattainment area may not be consistent with the boundary of the travel-demand network model.
- Not all roads are coded into the network.
- Model VMT may be estimated for different time periods (e.g., a.m. peak period or average weekday) than HPMS VMT (e.g., annual average day).

The adequacy of HPMS samples in a nonattainment area has been examined by FHWA, and new guidelines for sampling in the “donut area” have been released (FHWA, 1993). If the requirements of the HPMS manual, including its sampling procedure, are followed correctly, the areawide estimates of VMT for different functional classes included in HPMS should be adequate for areawide emissions estimation. HPMS universe data requires an average daily traffic (ADT) value for all sections of the primary arterial system. However, the VMT estimation procedure developed from sample expansion does not take advantage of ADT data for segments not included in the sample. When using HPMS, VMTs for rural minor collector and rural as well as urban local roads have to be estimated using other procedures. Alternative approaches for estimating local road VMT are addressed in Chapter 8. When VMT is needed for smaller subareas within the nonattainment area, as in the case of photochemical dispersion modeling, HPMS is not adequate.

Level of Accuracy

VMT from the travel forecasting models may disagree with that from HPMS by as much as 20 percent—this margin of difference may be even greater if analysis is carried out for each functional class of roadway. Given that many local links are not coded into the network, trips may be assigned from these routes onto the coded routes. The differences obtained from the traffic counts, and the counts themselves, may be subject to error, particularly if they are not updated as regularly as the emissions regulations require them to be. Therefore, because the traffic counts and the VMT are probably both in error, it is not clear by how much either one is actually in error and what the accuracy of either one is.

A major source of difficulty in calculating VMT relates to the geographical area of the nonattainment region as compared with the metropolitan or planning area. Typically, they are not the same, and data may well not be available for the whole region under consideration. There are problems associated with applying conventional urban models to rural sites, where trip-making characteristics are somewhat different. It may, therefore, be necessary to develop estimates of VMT on the basis of different stratifications, such as functional class of roadway by area type.

Estimates of local VMT represent a major problem for air quality planners. About 10 to 15 percent of urban travel occurs on local roads; therefore, failure to include local VMT will result in a serious misestimation of emissions. The regional transportation models typically represent local roads by centroid connectors that are abstractions used to move traffic into and out of the TAZs. As a result, interzonal travel that occurs on local roads is usually incorrectly represented, and much of it will actually be assigned to the arterial system. In addition, intrazonal travel and mileage within a zone are not estimated, because intrazonal trips are not assigned to the network and are, in fact, ignored after they are identified in trip distribution. This is a serious factor in considering the effects of cold starts, particularly if the analysis is being undertaken for the morning peak period. When much cold-start operation takes place on local streets and intrazonal trips normally operate entirely in the cold-start mode. A more detailed discussion of this problem appears in Chapter 8 of this report.

For CO nonattainment areas, the stipulations are for accurate, annual VMT forecasts for every year until attainment is reached. Travel forecasting models are usually applied for the base year and some year or years well into the future, and it is, therefore, likely that interpolations for intermediate years may be imprecise.

It is critical to provide estimates of travel for different periods of the day, particularly for peak/off-peak comparisons. Although there is no time-of-day scheduling built into the travel forecasting models, it is possible, through manipulation, to estimate travel demand for different periods of the day. There are four basic approaches to this—directly factoring the output of traffic assignment, trip table factoring, trip-end factoring, and direct generation. There is little information on the accuracy of these techniques; this issue will be addressed in testing the effects of aggregation in Chapter 7.

Temporal resolution is important because measures to reduce emissions tend to have the greatest proportional effect during the peak periods, when emissions are higher. If this is averaged over a longer time, the emissions reductions achieved will not be as evident. Further, stratification of VMT by time of day is essential if the UAM is to be used.

No reflection of seasonal variation can be considered in the travel forecasting models. Generally, the travel forecasting models were set up to represent travel on a midweek spring or fall day. To meet the emissions modeling requirements for summer and winter data, seasonal adjustment factors on the basis of variations in traffic counts, may be used to convert VMT from one time to another.

There is no common source of VMT data stratified by grid, as required by airshed models. Regional travel forecasting models incorporate a system of TAZs. These are loosely on the basis of the census geography of the area, and these traffic zones are primarily for aggregating socioeconomic data.
The links of a roadway network are not usually grouped according to these zones. This is a major problem with using VMT data from the travel forecasting models in the airshed modeling process.

**Data Type: Vehicle Class/VMT Mix and Vehicle Age Distribution**

**General Description**

Emission rates vary according to the characteristics of a vehicle. Of particular importance are the size and weight of the vehicle, the type of fuel used, and the age of the vehicle. MOBILE5a identifies eight classes of vehicles and assigns a different emission rate to each class. Ideally, VMT should be stratified by these eight classes in order to take full advantage of MOBILE5a’s emission rates.

The eight classes of vehicle for which MOBILE5a provides emission rates are as follows:

1. LDGV—Light-Duty Gasoline Vehicle.
2. LDGT1—Light-Duty Gasoline Truck, Type 1.
3. LDGT2—Light-Duty Gasoline Truck, Type 2.
4. HDGV—Heavy-Duty Gasoline Vehicle.
5. LDDV—Light-Duty Diesel Vehicle.
6. LDYT—Light-Duty Diesel Truck.
7. HDDV—Heavy-Duty Diesel Vehicle, and
8. MC—Motorcycle.

The age of a vehicle reflects the year the vehicle was built, the emissions standards applied at the time, and the emissions control technology used. The mileage of the vehicle will reflect the deterioration of the effectiveness of the emissions control system. Both are important components in calculating emissions rates.

Ultimately, there needs to be a determination of the levels of use of vehicles of particular classes, age, and so forth by functional class of roadway and time of day, if that level of detail is required. To summarize, the information required on vehicle mix is as follows:

- **Class of vehicle.**
- **The age and mileage accumulation rate of the vehicle.**
- **The fuel type used,**
- **Air-conditioning use,**
- **Trailer towing,**
- **Basic exhaust pollutant-emission rate,** and
- **Vehicle use levels.**

**Geographic Detail**

This information is usually only available on an areawide basis; it would be desirable to have the information by functional class of roadway.

**Uses in Air Quality Planning**

The fraction of VMT accumulated by each of the eight vehicle classes is to be specified as an input for the emissions-factor models. Default values are available, although it is preferable for local agencies to develop their own rates.

Mileage accumulation rates and/or registration distributions by vehicle type and age must also be specified, or the default values from MOBILE5a can be accepted. MOBILE5a incorporates deterioration functions to reflect the effect a vehicle’s mileage has on its emissions.

**Current Practices and Sources of Data**

The motor vehicle registration department in each state and local jurisdiction maintains areawide, aggregate data. The characteristics identified in the registration data, however, may not match the vehicle classes used by MOBILE5a, and registration data do not contain mileage information.

MOBILE5a calculates a default VMT mix on the basis of national data reflecting registration distributions and mileage accumulation rates by age for each vehicle type, total HDDV registrations and annual mileage accumulations by weight class, diesel sales fractions by model year, the fraction of travel by each vehicle that is typical of urban areas, and total fleet size by vehicle type.

MOBILE5a uses national average mileage accumulation rates and registration distributions by age. Areas with an I/M program will have information on mileage rates, because mileage is recorded as part of the inspection procedure. Until this information becomes available in an appropriate form, most areas will have to continue to accept MOBILE5a default values. MOBILE5a incorporates basic emission rates in the form of linear equations, consisting of a zero-mile intercept and one or two deterioration rates to reflect the increases in emissions with mileage. These equations are based on the relevant federal emissions standards and the emission-control technologies characterizing the fleet in various model years.

To determine vehicle classification by functional class, the primary source is the vehicle classification-count program in each state. This consists of counts carried out over a certain period, usually for the higher functional-class roads. The frequency of these counts varies depending on the authority concerned, although it is probable that the air quality regulations will imply more regular counts are necessary for conformity.

Another use for vehicle registration and I/M data would be for identifying vehicles that may contribute disproportionately high emission levels. These so-called “superemitters” may be a serious hindrance to improvement of air quality even in areas where emission rates of new vehicles will decrease significantly. Few, if any, urban areas are explicitly accounting for these vehicles in their emissions studies.
Level of Accuracy

There are inconsistencies between the motor vehicle registration data and the classes used by MOBILE5a. EPA's eight vehicle classes do not match exactly those of classification counts. A conversion or matching scheme has to be developed. Traffic counting equipment cannot identify MOBILE5a classes, because vehicles are classified by the timing of axles as they cross the equipment and these counts cannot reflect the fuel used by a vehicle. Classification counts are usually done on higher classes of roadways, such as interstates and principal arterials. There is little available data on vehicle classification for minor arterials, collectors, and local roads. There is also little information on temporal or seasonal variation in vehicle characteristics on highway segments.

The use of the default values for VMT mix employed in the MOBILE5a model is an area of concern. These values may need to be adjusted to reflect specific, nonuniform area conditions. Until local data are available, these values will be the principal source, but work is needed to improve the accuracy of these estimates. Further discussion on VMT mix is presented in Chapter 8.

Data Type: Operating Modes

General Description

The operating modes of a vehicle are broadly classified into two categories: transient and hot-stabilized modes. The transient mode is further classified into cold-start and hot-start modes. Of particular importance is the determination of the fraction of vehicles operating in the warm-up phase following a cold start, because this is when excessive amounts of CO and HC are released.

A cold start is defined as the operation of a vehicle following more than 4 hr since the end of the previous trip for vehicles not equipped with a catalytic converter, and more than 1 hr for catalytic-converter-equipped vehicles. The warm-up or transient phase is defined by a standard driving cycle that is part of the FTP. This cycle represents the first 3.59 mi of a typical urban trip, lasting 505 sec at an average speed of 25.6 mph.

MOBILE5a requires the proportions of vehicles operating in each mode to be specified. Because the model is extremely sensitive to the cold-start portion of the operating mode distribution, particularly at low ambient temperatures, accurate estimates of operating mode fractions by time of day and geographical location are important.

Geographical Detail

This information should be made available by location within an urban area and by functional classification of roadway.

Uses in Air Quality Planning

The percentage of VMT accumulated in the cold-start, hot-start, and hot-stabilized modes is required for MOBILE5a.

Microscale emissions modeling requires the proportion of vehicles operating in each mode, by time of day, for each link or analysis area. This implies that information is needed on the time that has elapsed since the trip was started and the time between the start of the present trip and the end of the preceding trip.

Current Practice and Sources of Data

Estimating the percentage of vehicles in the various modes of operation is a complex task. For this reason, most areas use either the default values provided in the MORR E5 model or generally accepted variations for specific scenarios. Table 2-2 shows the four most commonly used vehicle type/operating mode combinations that MOBILE5a recognizes, together with the values developed from the FTP-75.

These vehicle type/operating mode values represent national averages and typically are used as defaults in MOBILE5a for regional emission calculations and 8-hr CO analyses. Other widely accepted standard splits are used for specific scenarios, as shown in Table 2-3. Again, given the difficulty of developing accurate estimates of their own, areas generally accept these default values; however, the use of these default values is not appropriate in many cases, especially for microscale CO analyses.

An accurate determination of the operating mode of a vehicle requires measurements of the engine temperature; such measurements are difficult to obtain. Studies have addressed some of these issues, but little work has been done recently. For example, a study in New Jersey in 1984 collected field data by stopping vehicles at roadside and measuring temperatures of engine oil and coolant (Brodtman and Fuca, 1984). Estimates of engine run times were also obtained from the drivers. The data were analyzed to develop operating mode fractions for six functional classes of roads.

Pioneering analytical work on cold starts was conducted by the Alabama Highway Department in The Determination

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Operating Mode (Notation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-catalyst</td>
<td>Cold-start (PCCN)</td>
</tr>
<tr>
<td>Catalyst/Non-catalyst</td>
<td>Hot-start (PCHC)</td>
</tr>
<tr>
<td>Catalyst</td>
<td>Cold-start (PCCC)</td>
</tr>
<tr>
<td>Catalyst/Non-catalyst</td>
<td>Stabilized (1.0 - PCCC - PCHC)</td>
</tr>
</tbody>
</table>

PCCN = 20.6%, PCHC = 27.3% and PCCC = 20.6% for FTP.
Table 2-3: Standard splits for specific scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>PCCN</th>
<th>PCHC</th>
<th>PCCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTP Day-Long Regional Analyses and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-Hour CO Analyses</td>
<td>20.6%</td>
<td>27.3%</td>
<td>20.6%</td>
</tr>
<tr>
<td>Peak Hour Analyses</td>
<td>50%</td>
<td>10%</td>
<td>50%</td>
</tr>
<tr>
<td>One Hour Special Event Analyses</td>
<td>100%</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>Hot-Stabilized Analyses (Interstates and</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Expressways)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*PCCN = 20.6%. PCHC = 27.3% and PCCC = 20.6% for*

of Vehicular Cold and Hot Operating Fractions (Ellis et al., 1978). This report used both observed and modeled data from various cities in Alabama and Boston to study cold starts in detail. This report provides extensive information on estimating the proportion of VMT occurring in cold-start mode by time of day, trip length, and trip purpose.

Other studies have examined the cold-start issue from the perspective of traffic on the roads, rather than the proportion of cold-start trips. The EPA’s report, Determination of Percentages of Vehicles Operating in the Cold Start Mode, provided information on how to estimate the duration of the cold-start portion as a function of soak time (Midurski and Casteline, 1978). It also provides estimates of the proportion of cold-start traffic for individual links, on the basis of the link’s location, the facility type, and the time of day.

Analytical attempts to develop operating modes for different types of roadway have focused on the time taken from the trip origin to the point of study (e.g., Benson, 1988). For example, it might be expected that on certain roads there will be more vehicles near the end of the warm-up phase. Benson found this to be the case for urban freeways and arterials. The University of Tennessee has developed software that modifies traffic assignment results by developing the distribution of vehicles according to their elapsed time from trip origins to each link in the network. MINUTP software also has this capability.

Level of Accuracy

The emission factor models are very sensitive to the operating mode of vehicles; therefore, planners must specify when and where on the network vehicles are in the cold-start mode of operation. It is common practice to use default values, but the limited studies done suggest there may be limitations to this method.

More accurate predictions of trips by trip purpose can be derived through the travel modeling procedure. For example, it might be expected that a high proportion of work trips are made in the cold-start mode of operation, particularly during the a.m. peak period. Further problems may arise because a large proportion of cold-start travel occurs on local streets not coded into the network.

Work trips can be estimated fairly accurately, because such trips are repetitive and many studies have concentrated on these trips. Non-work trips have generally been poorly estimated, given the complexity of the trips and the lack of up-to-date origin-destination data in most states. It is common in many transportation studies to combine trip purposes into one or two categories, although this aggregation leads to inaccuracies.

It is critical to determine trip ends for different periods of the day, particularly in the morning peak when it might be expected that there will be a large proportion of the total daily cold starts. During afternoon peak hours when many employees leave work, central business district (CBD) areas may have a high percentage of cold starts. Although there is no temporal resolution built into the travel forecasting models, it is possible, through manipulation, to determine trip ends by time of day, location, and trip purpose. However, this requires a significant departure from standard practice in time-of-day treatment in travel forecasting procedures. More discussion and analysis of time-of-day stratification of travel are presented in Chapter 7.

Standard procedure is to split trips by time of day immediately before assignment; however, trip distribution generally distributes work trips using the peak characteristics from the network, and non-work trips using off-peak network characteristics. When the trips are then allocated to the time just before assignment, some work trips are now allocated to the midday period, while some non-work trips are allocated to the peak period. Those work trips now allocated to the midday period were distributed according to peak congestion, which is inconsistent with the assignment, and the reverse problem occurs for non-work trips allocated to the peak. Mode choice, when it is also included, usually continues the estimation process consistent with trip distribution. In this case, not only may the LOS be wrong, but transit services operated only in the peak hour cannot be used by non-work trips, and the proportion of work trips actually made in the off-peak may be incorrectly estimated as using some of these peak-period transit services. Therefore, applying time-of-day factors just before assignment results in inconsistencies and errors in the transportation forecasts and makes it difficult to estimate trip ends by time of day.

The alternative to this process is to apply time-of-day factoring immediately following trip generation (or as part of trip generation), where this effectively results in allocation of the production and attraction trip ends to period, directly. This process assists in determining probable operating mode by time of day and substantially improves the consistency of the travel forecasting process. Under this procedure, trip distribution and mode choice are each run twice (or more) for each trip purpose once for each of the periods (minimally for peak and midday, or possibly for a.m. peak, midday, p.m. peak, and night), using the relevant network characteristics for each period. More discussion and analysis of time-of-day stratification of trips are presented in Chapter 7.
The problems associated with not accounting accurately for the proportion of vehicles in each mode of operation is particularly evident in microscale studies. It is crucial to determine how long vehicles have been traveling before they enter the link or intersection being analyzed. One possibility would be to develop a vehicle-use analysis that would focus on the time of day when trips originated. This could be done by relating the characteristics of the household members to trips of certain purposes. This would provide a way to estimate cold starts by time of day. Further discussion on improved methodologies for operating mode fractions is presented in Chapter 8.

**Data Type: Trip-End Data**

**General Description**

Substantial amounts of pollutants are emitted during the start-up process of vehicles. There are also hot-soak emissions when an engine is turned off at the destination. The emission factors of MOBILE5a incorporate the effects of starting an engine (cold-start emissions) and turning it off (hot-soak emissions) with the exhaust pipe and running loss emissions that occur when a vehicle moves along roadways. The model reports emissions in grams per mile of travel, and trip-end emissions are included in the rates, assuming average travel distances. There is usually no attempt to separate the emissions that occur when a vehicle is in a stopped condition from those when it is moving.

The emission factors of EMFAC7F incorporate the effects of engine start-ups as instantaneous "puffs" associated with the very beginning of a trip. The intention of this methodology is to assign the higher-than-normal emissions to the locations where they occur. For this purpose, VMT estimates alone are not sufficient. Trip-end estimates for defined geographic areas are also needed. In a few cases, MOBILE5a has been used in a disaggregate manner to capture the effect of start-up and hot-soak emissions associated with trip-ends. The Metropolitan Washington Council of Governments (MWCOG) uses a procedure that estimates trip-related emissions in three parts or components—startup, running, and hot-soak. This agency determines emission rates for each of these components using MOBILE5a. Data on trip origins and trip destinations and VMT estimates are needed for this approach. The excess (or difference) in emissions between 100 percent cold-transient (or 100 percent hot-transient) mode and 100 percent hot stabilized mode of operation during 505 sec, or 5.39 mi, at 25 mph is used as the start-up emissions (grams per trip) at trip origin. Start-up emissions include HC, CO, and NO. The VMT is multiplied by the emission rate (grams per mile) for 100 percent hot-stabilized mode. Hot-soak emission rates for HC (grams per trip) are obtained from MOBILE5a and used in conjunction with trip destinations. The procedure is documented in detail in a report written by the agency (MWCOG, 1993).

To summarize, the trip-end data requirements for some air quality analyses (primarily using EMFAC7F) are:

- Time of day,
- Trip purpose (as a means to associate trip length and hot or cold starts to the trip-end),
- Duration, and
- Vehicle type.

This information is used to determine

- Total number of vehicle trips;
- Number of hot and cold starts and their spatial allocation;
- The trip length taken as the time from the origin to the destination; and
- The diurnal evaporative emissions, on the basis of the length of time a vehicle is parked at the trip-end location.

**Geographical Detail**

The geographical detail required is at grid level for dispersion models and, preferably, at a finer level of resolution for microscale studies.

**Uses in Air Quality Planning**

Trip-end data are not required as input by MOBILE5a; however, trip-end data are required when EMFAC7F is used and for certain microscale studies. (As discussed earlier, MWCOG uses trip-end data to estimate start-up and hot-soak emissions using MOBILE5a.)

**Current Practice and Sources of Data**

Trip-end data are difficult to estimate accurately because travel and parking characteristics are complex. The trip generation step of stepwise travel demand models is the major source of trip-end data for different geographic areas. Trip purpose plays an important role in trip-end estimation and in determining the temporal distribution. For instance, work trips can be estimated fairly accurately—they are repetitive and many studies have concentrated on these trips. Information on the journey to work is available from the 1990 census and available local studies.

Another area of ongoing research is that of forecasting travel demand using dynamic microsimulation. This involves identifying the changes in the socioeconomic and demographic characteristics of a household and determining the effect of these changes on vehicle ownership and use. This procedure requires considerable data, preferably obtained from a panel survey.
Level of Accuracy

Accurate information is needed on the length of time that a vehicle is parked by time of day and location in order to determine whether the next start is a cold or hot start. Trip-end information is also needed in order to determine the hot-soak emissions when the engine is turned off. Trip-end information can be approximated to the level of the TAZs used in the modeling procedures, but, if a finer resolution is required, as in hot-spot analyses, this information is inadequate.

The travel forecasting models do not provide information on the duration of parking or the vehicle class. It may be possible to examine trip attraction purposes and make certain assumptions about the length of time a vehicle will be parked there (e.g., 8 hr for work-based trips); however, there is doubt over the accuracy of this, particularly for non-work purposes where parking durations may vary widely. A comprehensive origin-destination travel survey includes information on parking, however, such travel surveys have not been conducted in most urban areas in recent years.

Data Type: Capacity

General Description

Capacity is the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway under prevailing roadway, traffic, and control conditions. Capacity is required for the calculation of speed-flow and delay relationships.

Each roadway has a different capacity depending on its design speed, functional class, number and width of lanes, topography, vehicle mix, and driver population. For non-freeway roads, the capacity is determined by the capacity of the intersections along that road. A saturation flow rate is calculated in this case that determines the maximum number of vehicles that can pass through the approach per hour of green time.

Geographical Detail

Capacity is closely related to functional class. For some types of roads, capacity would be required only by functional class as a per lane figure, then to be multiplied by the number of lanes. Area type may also enter into the requirements, where speed limits or other factors affect capacity. On the other hand, for arterials and lower-level facilities, capacities are needed on a link-by-link basis.

Uses in Air Quality Modeling

Capacity is required in the calculations of speeds and for determining delay.

Current Practice and Sources of Data

The primary source of data is the 1985 Highway Capacity Manual, which is being revised. This contains methodologies for calculating capacities of different roadways and intersections. This publication is the subject of ongoing research and review.

Level of Accuracy

The calculation of capacity is complex but critical to the travel forecasting modeling process. The V/C ratio is used in the computation of speeds. (See also the earlier discussion of Speed Estimation.) Because the interrelationships between speed, capacity, and volume are not well understood, the accuracy requirements for capacity are not easily defined. Given that the traditional approach in the definition of highway networks is to assign a per lane-hour capacity by functional class, the network-based capacities usually will be very inaccurate.

One major problem associated with the travel forecasting output is that V/C ratios may exceed a value of 1. Such values are meaningless, other than for very short periods or as input volume divided by output capacity for a facility of significant length. Therefore, when such values are produced routinely by the software, it invalidates the output of the models.

Empirical observations may conclude that traffic volume exceeds estimated capacity, particularly on freeways during certain times of the day. This may occur because drivers are not following other vehicles at the minimum headways assumed for capacity calculations. Calculated values of the Highway Capacity Manual are being updated on the basis of recent studies.

Data Type: Queuing

General Description

When demand exceeds capacity for a period or an arrival-time headway is less than the service time at a specific location, a queue is formed. This phenomenon occurs at intersections, bottlenecks, accident sites, and other locations. For the purposes of air quality modeling, the critical element is to determine the idle time of a vehicle while queued—CO and HC emissions are at their highest when vehicles are idling.

The input requirements for queuing analysis include the following:

- Mean arrival value in vehicles per hour or seconds per vehicle.
- Arrival distribution (deterministic or probabilistic).
- Mean service value.
- Service distribution, and
- Queue discipline.
Information also is needed on the characteristics of the intersection. The following attributes should be determined:

- Type of intersection and,
  - For signalized intersections,
    - Traffic movements permitted during each signal interval,
    - Cycle time and duration of each signal phase,
    - Saturation flow (i.e., the rate of discharge from the junction),
    - Presence or absence of right turn on red, and
    - Signal offset.

Street geometric attributes include

- Number of lanes,
- Length of segment, and
- Distance between intersections.

Street traffic operations attributes include

- Average start-up loss time for the first vehicle in queue,
- Existing free-flow cruise speed as determined through empirical observations, and
- Turning and through movement volumes discharging at an intersection.

Geographical Description

The information is required at the level of an intersection.

Uses in Air Quality Planning

Idle emission factors are calculated for each vehicle type on the basis of emissions for vehicles traveling at 2.5 mph. These factors are applied to the number of vehicles queued at the intersection. Average per vehicle delay is required for CO modeling. This is the excess time vehicles spend on the network because of operation at speeds below the free-flow speed.

Current Practice and Sources of Data

Current practice in many areas is to develop factors to convert local traffic counts into peak- or 8-hr data, as the situation demands. These counts will also be adjusted to account for seasonal variations. Typically, this is done directly or by taking the output of another network model and adjusting the figures accordingly.

Microsimulation Travel Models

Regional travel forecasting models cannot provide the information needed for detailed CO studies. Several microscale simulation models aim to replicate the behavior of traffic under certain conditions. TRANSYT 7F is a microsimulation model that simulates the flow of traffic on arterial streets. It provides inputs for CAL3QHC. To run TRANSYT 7F, the following inputs are required:

- Traffic volumes at the network entry point,
- Saturation flows,
- Existing signal parameters,
- Existing cruise speeds, and
- Intersection geometry.

Outputs of the model include

- Hourly information on traffic volumes,
- Average queue lengths, and
- Cycle lengths.

Level of Accuracy

The accuracy of these predictions depends on the data required as input for the models as well as the methodology employed by the models themselves. The information should be validated with empirical observations.

Data Type: Travel Characteristics

General Description

TCMs are designed to reduce VMT, encourage HOV travel, encourage travel by other (transit and nonmotorized) modes, and change the time when people travel. To measure and predict the effect these factors will have on emissions, specific data are required on travel characteristics. To implement measures that change the way people travel and allow estimation of the effects of TCMs on air quality, it is necessary to understand how and why people travel.

The CAAA and Conformity Rule have identified characteristics that would be useful in this context. The information can be classified as follows:

- Vehicle occupancy rates (Employers of 100 or more employees in areas rated as Severe and higher for nonattainment of ozone are required under the CAAA to increase average passenger occupancy per vehicle by at least 25 percent above the average for all work trips in the area by 1996. This measure is aimed at reversing the decline in average automobile-occupancy rates, particularly for the journey to work, which now averages 1.1 persons per vehicle [Research Triangle Institute, 1991]),
- Distinguishing between person trips and vehicle trips (Transportation models generally incorporate measures of vehicle trips, which implies that measures aimed at shifting trips to nonmotorized modes cannot be analyzed),
Information on transit systems and nonmotorized modes.
- HOV lane provisions.
- Parking measures.
- The effect of pricing and the LOS (to determine the potential effect of employer-based measures at reducing trips).
- Vehicle ownership and use levels, and
- The effect of the available transportation itself on the travel decision process.

Geographical Description

This will depend on the specific project and pollutant concerned. If TCUs are being analyzed regarding their effectiveness at reduce total VMT, travel over the entire area must be considered. If the analysis requires monitoring the effect of improved signalization on intersection performance, the information is required at the level of the intersection.

Uses in Air Quality Modeling

The effect of changes in travel characteristics is reflected in the VMT and vehicle trips required to calculate regional emissions estimates. Currently, air quality models cannot account directly for the effects of these changes. Air quality models require estimates of VMT and vehicle-trip changes to be estimated by the travel-demand models in order to estimate the effects of TCM strategies on air quality.

Current Practice and Sources of Data

The major agencies that collect data on travel characteristics and the scope of their programs are reviewed below.

The Bureau of the Census Journey-to-Work Division provides detailed information on the journey to work for all modes. This information includes the principal mode used, travel time, time of departure, and carpool size, occupation, industry, income, household characteristics, demographic characteristics, and vehicle availability. Respondents are asked about their usual means of transportation to work. Research suggests that information pertaining to what the respondent did on the previous day will give a more accurate reflection of travel upon a particular day. Data are collected on the “long form” of the decennial census from a sample of approximately 12 percent of the population. Data are provided at varying levels of disaggregation, with the smallest level being the TAZ.

The National Personal Transportation Survey (NPTS) is a national survey of trips and travel for 18,000 (25,000 in 1995) randomly sampled households, conducted approximately every 7 years. The NPTS provides information on the characteristics of those traveling and the characteristics of the trips taken, such as trip purpose, length, time, time of day, and vehicle occupancy. Information can be disaggregated to the county (MSA) level but no lower, requiring extensive manipulation for use at the local level. Because validity is established at the national level and samples are very small at the MSA or county level, problems of validity will exist for these levels of disaggregation. However, add-on samples may be purchased by states and MPOs and can be provided at the TAZ level, with validity dependent on the size of the add-on sample.

State DOTs and MPOs maintain inventories of various characteristics of their transportation systems. The CAAA and Conformity Rule will have implications for the frequency and accuracy with which certain of these characteristics are recorded in nonattainment areas.

Level of Accuracy

The current travel forecasting process is sensitive to certain parameters and reflects changes involving these parameters. These include the effects of travel costs, travel times, and access and egress facilities on the choice of travel mode. To the extent that any TCM can be represented in terms of changes to travel times, travel costs, or access and egress characteristics, the models can provide some measure of likely response. The process is not sensitive to measures aimed at encouraging changes to nonmotorized modes. These could be included if the models were extended to include nonmotorized modes from trip generation forwards, if nonmotorized modes were included in the mode-choice model alternative sets, and if travel time could be determined accurately for these modes.

There is no account taken of the effect that the available transportation system has on the travel-making characteristics of an area. As a consequence, no account can be taken of increased trip making because of decreased congestion or decreased trip making because of increased congestion. The Conformity Ruling has brought this area into focus and research is underway.

REFERENCES

