NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 394

Improving Transportation Data for Mobile Source Emission Estimates

Transportation Research Board
National Research Council

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Improving Transportation Data for Mobile Source Emission Estimates

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration, U.S. Department of Transportation.

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FOREWORD

By Staff
Transportation Research Board

This report describes research carried out under NCHRP Project 25-7, *Improving Transportation Data for Mobile Source Emissions Estimates.* The report provides an overview of federal statutes and policies which form the foundation for air quality planning related to transportation systems development. It also provides a detailed presentation regarding the use of federally mandated air quality models in estimating mobile source emissions resulting from transportation development and operations. The authors suggest ways in which current practice and analysis tools can be improved to increase the accuracy of their results. They also suggest some priorities for additional related research. Planning practitioners and policy analysts should find the report helpful in integrating transportation data into air quality analyses. State, metropolitan, and local transportation planners should find the material useful in improving their understanding of and in avoiding potential analytical difficulties associated with assessing project or plan conformity. Finally, the report should assist federal agency practitioners in their efforts to improve analytical methods and tools for determining conformity. The report will also serve as a basic educational resource for current and future transportation and air quality modeling.

The Clean Air Act Amendments of 1990 (CAAA) require states to attain and maintain ambient air quality standards. Geographic areas not meeting air quality standards are designated as nonattainment areas and must satisfy certain requirements and deadlines, depending on the severity of the air quality problem. Mobile sources, such as automobiles and other vehicles, are considered a significant component of the nonattainment problem, and consequently, the transportation sector is expected to provide appropriate emissions reductions. Decisions on how to achieve reductions reflect the different levels and types of analyses for local conditions, such as attainment status, the size and complexity of the area, and the type of pollutants involved. Also, various activities, such as emission-inventory development, transportation control management (TCM) strategies, "conformity" assessments, and state implementation plan development, have different analysis needs. To meet all these requirements, various transportation data are needed. Much of this information, however, is used to support analyses in ways not originally intended. The use of transportation data inputs into the air quality modeling process may produce inaccuracy in these analyses and the conclusions they support. For example, the speed outputs from travel models, which are subject to significant error, are among the most crucial inputs into the mobile source emissions models, such as EPA's MOBILE 5 model or the California Air Resources Board's EMFAC model. Although these errors do not significantly affect the results or conclusions of the travel models within the metropolitan transportation planning process, they could affect accuracy and reliability when employed as a major input factor in the air quality models.

In addition, air quality modeling often requires transportation data that are difficult to obtain or may not even exist. In such cases, standard default values for transportation data, such as "cold starts" and vehicle-mix and -age characteristics, are used. These default values may or may not accurately reflect the conditions within the particular area for which they are employed. Also, the CAAA identifies estimates of vehicle-miles traveled (VMT) as an important component in the attainment of ambient air quality standards, but no accepted technique exists for estimating VMT on local roads. Local roads are those low-volume roads that serve neighborhoods. Although they do not carry the higher speed, high-volume traffic that freeways, major arterials, or collectors carry, they represent the greatest number of lane miles of any region's roadway network. They also serve much of the residential developments which represent the origins and destinations of many trips within these regions. Local roads are assumed to carry one-third of the VMT in urbanized areas, usually under the high-emissions conditions of low speeds and high idle times. The effects of these problems on emissions estimates for nonattainment areas with differing characteristics are not well understood.

Because transportation modeling and air quality modeling interrelate, a better understanding of this relationship and the underlying assumptions used in individual modeling processes is needed. Given the limitations of the air quality models that must be used, a priority is to examine the effect of transportation data on the estimates from these air quality models and on air quality planning.

Under NCHRP Project 25-7, *Improving Transportation Data for Mobile Source Emissions Estimates*, the University of Tennessee, Knoxville, formed a research team with its subcontractors. In this report, the research team has described the major statutory and regulatory requirements that affect transportation and air quality planning as currently practiced as well as and the variables and methods employed by state, regional, and local transportation and air quality planners to ensure conformity with federal air quality standards. The team then discusses the results of an analysis of uncertainty and errors associated with the use of the U. S. Environmental Protection Agency's (EPA's) MOBILE5a model, which is used to determine conformity of transportation programs and plans with federal requirements. In the concluding chapters of the report, the research team has provided recommendations for improving the methods and tools used and suggests priorities for further research.

CONTENTS

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The authors are also grateful to several staff members of the Transportation Research Board who were directly involved with this NCHRP project. They include Ronald D. McCready and Crawford F. Jencks. Stephen E. Blake and Andrew Lemar also were associated with this project for brief periods.

OVERVIEW AND ORGANIZATION

This report provides information on estimating mobile source emissions using MOBILE5a, a model developed by the U.S. Environmental Protection Agency (EPA), and gives special attention to travel-related inputs to this model. The major focus of this research study was the uncertainty or error associated with emissions estimates developed for an emissions inventory, a conformity analysis, or both by local and state agencies using MOBILE5a.

This report addresses the following topics:

- Background information on legislation and requirements, key variables and methodologies, and the current state of practice at state and local levels (Chapters 1, 2, and 3);
- Uncertainty or error involved with the use of MOBILE5a (Chapters 4, 5, 6, and 7); and
- Improvements in methodologies and recommendations for further research (Chapters 8 and 9).

BACKGROUND

Chapter 1 presents information on recent legislation and requirements related to air quality analysis for mobile source emissions. Chapter 2 examines the process and procedures used for calculating emissions from mobile sources and focuses on key travel-related variables that must be quantified for this purpose. Methodologies commonly used for estimating each transportation variable are examined in detail. Chapter 3 presents the findings of a survey of the current practices of state departments of transportation (DOTs) and local metropolitan planning organizations (MPOs). Chapter 3 also reviews various sources of error and interrelationships of different components of the travel modeling process commonly used to generate travel-related inputs to MOBILE5a. These three chapters are designed to provide a reader with a sound understanding of the requirements, methodologies, and state of the art related to inputs to MOBILE5a.

UNCERTAINTY AND ERROR ANALYSIS

Chapters 4, 5, 6, and 7 represent the main concern of the research; these chapters examine how emissions estimates produced for an emissions inventory, a conformity analysis, or both are affected by errors from various sources. The sources of error can be grouped into two broad classes—external and internal with respect to MOBILE5a. The external sources of error involve the input variables of MOBILE5a, such as speed, vehicle-miles of travel (VMT), vehicle classification, and operating mode fractions. Chapters 4, 5, and 7 discuss external sources of error while Chapter 6 discusses speed correction factors (SCFs), which constitute an internal source of error. Chapter 4 quantifies how the emission rates for carbon monoxide, hydrocarbons, and oxides of nitrogen vary because of variations in the estimated values of input variables. The analyses presented in Chapter 4 show how errors in input variables alone can cause differences in the results obtained from MOBILE5a. Chapter 5 examines two specific input variables—speed and VMT mix—and quantifies the magnitude of error that can be expected in the estimated values of these input variables when using common methodologies. Chapter 7 focuses on the stepwise travel-modeling process widely used in urban transportation planning and examines different procedural variations with respect to the aggregation of data and their effects on the resulting estimates of VMT and emissions. The analysis in Chapter 7 is based on a case study of an urban area.

Chapter 6 deals with one internal source of error—SCFs. Although the internal calibration of MOBILE5a is outside the reach of transportation engineers and planners working for state DOTs and MPOs, MOBILE5a is an empirically developed model, and the model development process itself has been exposed to various sources of error. This project was able to analyze the data set used to derive SCFs, which the model uses internally to determine responses to externally input speed estimates. Chapter 6 presents the findings of a statistical analysis of this data set and provides valuable information on confidence intervals associated with SCFs.

IMPROVED METHODOLOGIES AND RECOMMENDATIONS

Although the primary focus of this study was on error analysis, effort was made to identify improved methodologies for use by transportation engineers and planners in reducing errors in estimation of four key input variables. The specific variables examined for this purpose were operating mode fractions, VMT on local roads, speed, and types of vehicles (VMT mix). Discussion of these improved methodologies is presented in Chapter 8. Conclusions and recommendations for further research are presented in Chapter 9.

CHAPTER 1

REQUIREMENTS OF THE FEDERAL LAWS

INTRODUCTION

The requirements of the 1990 Clean Air Act Amendments (CAAA) establish significant new challenges to transportation and air quality modelers to improve estimates of traffic and emissions from mobile sources. To show conformity to federal laws, modelers must project mobile source emission inventories for the state implementation plan (SIP) process and calculate the differences in emissions between the Build and No-Build conditions of transportation plans, programs, and projects.

The CAAA established a process that requires nonattainment areas to reduce emissions in order to attain the National Ambient Air Quality Standards (NAAQS). These emissions are divided into three categories—mobile, stationary, and area sources. The SIPs will establish emission limits (also called emission budgets) for the nonattainment areas. Separate emission budgets will be established for each emission source category. Typically, the state air quality agencies are responsible for developing the SIPs and their emission budgets. State departments of transportation (DOTs) or the regional planning agencies provide the traffic and emissions data to state air quality agencies for use in calculating the mobile source emissions budget. This calculation can vary from a relatively simple approach, such as applying one mobile source emission factor to the Highway Performance Monitoring System (HPMS) traffic data, to a more detailed analysis, such as applying individual mobile source emission factors to each roadway link's traffic data as developed by a travel demand forecasting model.

The conformity requirements have established critical tests for comparing the Build and No-Build conditions of transportation plans, programs, and projects. These tests require a demonstration that the Build emissions are less than the No-Build emissions. The No-Build scenario represents the current transportation system, including future projects that have received environmental approvals under the National Environmental Policy Act (NEPA) process. The Build scenario comprises the No-Build scenario and all the new transportation projects being proposed.

The conformity criteria are difficult to meet for volatile organic compounds (VOCs) and particularly difficult to meet for oxides of nitrogen (NO_x). The NO_x criteria are difficult to meet because, unlike VOC and carbon monoxide (CO) emission rates, NO_x emission rates increase with increased speeds, which are the point of implementing highway system improvements.

AIR QUALITY STANDARDS

Mobile source emissions are significant sources of the air pollutants, ozone and CO. Many areas of the country experience air pollution levels that exceed the health-based standards for these pollutants. Typically, a mesoscale or gross burden analysis is conducted to estimate regional ozone precursor emissions and a microscale analysis is conducted to calculate site-specific CO concentrations.

The EPA estimates national emissions of several primary pollutants (including CO, lead, NO_x, particulate matter, sulfur dioxide, and VOCs) yearly. These data are used to assess historic trends of criteria pollutants. Mobile and stationary source emission trends indicate a reduction in recent years; area source emissions have demonstrated little change over time.

Ozone

The Environmental Protection Agency (EPA) has set the NAAQS for ozone at 0.12 parts per million (ppm) for a 1-hr period not to be exceeded more than 3 times over a continuous 3-year period. All of the NAAQS are presented in the *Code of Federal Regulations* (40 *CFR* Part 53).

Ozone is not emitted directly by mobile sources. It is formed in a complex chemical process that occurs when precursor emissions of VOCs and NO_x react in the presence of sunlight and heat. Because heat and sunlight are important factors in ozone formation, violations of the ozone standard occur almost exclusively in summer. Although both pollutants (VOCs and NO_x) play significant roles in ozone formation, EPA requirements have focused on reducing VOCs as the most effective strategy to achieve the ozone standard. The CAAA, however, require states to develop SIPs that evaluate reductions in all of the components that contribute to ozone (VOCs and NO_x). Approximately 50 percent of these ozone precursor emissions come from mobile sources.

Ozone adversely affects lung functions. Effects can include a sore throat, chest pain, cough, and headache. High levels of ozone can decrease heart rate, oxygen intake, and maximum work load capability. Although the average person may experience these adverse effects, changes in lung functions are likely to be greater for the young, the elderly, and those with lung diseases.

Carbon Monoxide

The NAAQS for CO is 35 ppm for a 1-hr period and 9 ppm for an 8-hr period, each not to be exceeded more than once per year. CO is a pollutant with localized effects. Typically, a microscale analysis is conducted to calculate CO concentrations at specific receptor locations, usually near locations with traffic congestion. Typically, more than 90 percent of CO emissions come from mobile sources. CO, a colorless, odorless gas, is a by-product of incomplete combustion.

The adverse health effects of CO are a result of its combination with blood hemoglobin to form carboxyhemoglobin. This compound interferes with the life-sustaining transfer of oxygen from the lungs to the body tissues and with the return of carbon dioxide from the tissues to the lungs. Relatively small amounts of CO can significantly interfere with essential cardiovascular-respiratory functions. Brief exposure to high levels of CO can impair vision, physical coordination, and the perception of time.

CLEAN AIR ACT AMENDMENTS

On November 15, 1990, the President signed the CAAA of 1990. These amendments established a new process for relating ground-level ozone, one of the most significant air quality problems, to the transportation system. One of the key features of the law is that it "classifies" nonattainment areas with similar pollution levels for each criteria pollutant. This classification system matches pollution control requirements and attainment deadlines with the severity of an area's air quality problem. These classifications include Moderate, Serious, Severe, and Extreme. This system was designed to address nonattainment problems by imposing a combination of prescribed measures that address the severity of the air quality problems while giving the states ultimate responsibility for and flexibility in solving the problems. Contingency measures will be invoked if the states fail to plan adequately or fail to achieve attainment by the prescribed attainment date. The EPA's *Ozone and Carbon Monoxide Areas Designated Nonattainment* (1991) listed the initial classifications of nonattainment areas. Because of the implementation of emission control measures and new air quality monitoring data, several nonattainment areas have requested or are requesting that the EPA reclassify them. Therefore, planners should contact the EPA regional offices in order to ascertain the current classification of an area.

Nonattainment Areas

Several areas in the country, previously designated as ozone nonattainment areas, were not classified by the EPA in 1991. The CAAA designated these areas as "transitional areas," as "incomplete or no data nonattainment areas," or both. Transitional areas are areas that, before enactment of the CAAA, were designated as ozone nonattainment areas, but did not have *monitored ozone data* between January 1, 1987, and December 31, 1989, that supported a classification of Marginal or higher. Incomplete or no data ozone nonattainment areas are areas that were designated as ozone nonattainment areas, but did not have *acceptable ozone monitoring data* between January 1, 1987, and December 31, 1989, that supported a classification of Marginal or higher. The EPA expects these areas to submit redesignation requests when the appropriate monitoring data and documentation are available.

The CAAA also established two classifications (Moderate and Serious) for CO nonattainment areas. The Moderate classification was divided into two groups—moderate less than 12.7 ppm and moderate greater than 12.7 ppm. Planners should contact the EPA regional offices in order to ascertain the current classification of the CO nonattainment areas. Several areas previously were designated as CO nonattainment areas, but were not classified as Moderate or Serious. The CAAA designated these areas as "unclassified CO nonattainment areas." Unclassified CO nonattainment areas are areas that did not have monitored CO data between January 1, 1988, and December 31, 1989, that supported a classification of Moderate or Serious. The EPA expects these areas to submit redesignation requests when the appropriate monitoring data and documentation are available.

State Implementation Plan Submissions

The CAAA require states to submit numerous SIP revisions that must include measures to reduce air pollutants. Several of these SIP revisions specifically address the mobile source contribution to the ozone problem. The first of these SIP revisions required the submission of a 1990 State Emissions Inventory composed of four parts: stationary point sources, stationary area sources, mobile sources, and biogenic sources. This inventory was to serve as the baseline for the CAAA-required reductions.

The second SIP revision, due in November 1993, required states with nonattainment areas classified as Moderate or higher to provide detailed plans demonstrating how *a reduction of 15 percent of their adjusted 1990 emission levels (adjusted to reflect the CAAA-required programs) would be achieved by 1996.*

The third SIP revision, due in November 1994, required states to provide detailed plans demonstrating how *a 3 percent per year reduction from 1990 emissions levels, commencing after 1996*, will be achieved in states with nonattainment areas classified as Serious or higher. In addition, states with Serious or higher nonattainment areas were required to submit a plan demonstrating how additional reductions, as demonstrated by urban airshed modeling (UAM), will be achieved. Although the CAAA established minimum percentage reduction requirements for nonattainment areas, UAM (which is being conducted by the states and the EPA) is required in order to identify the exact reductions in ozone precursors necessary for attainment.

The UAM results were not completed in time for the November 1994 SIP submissions. As a result, many states are preparing SIP revisions that meet the minimum CAAA requirements. In this revision, states with nonattainment areas classified as Serious or higher must provide detailed plans demonstrating how a reduction of 24 percent of their adjusted 1990 emission levels will be achieved by 1999. This SIP revision will allow the states to fulfill their CAAA responsibilities until the UAM results become available.

States will not know the final emission reduction requirements for their nonattainment areas until the UAM results are available; however, substantial reductions in the mobile source component of the emissions inventory will be necessary to meet the minimum reduction requirements of the CAAA as well as to attain the reductions by the prescribed deadlines. Congress recognized the need for reductions of mobile source emissions and, in the CAAA, it expanded the responsibilities of the U.S. DOT and the EPA for ensuring that transportation plans, programs, and projects respond to the goals of SIPs. This responsibility is reflected in the requirements for "conformity." In addition, Congress set forth many new requirements for new automobiles as well as requirements for more sophisticated inspection and maintenance (I/M) programs. Congress has also mandated other mobile source programs that will require clean fuel programs, employee trip reduction programs, transportation control measures (TCMs), and limitations on vehicle-miles of travel (VMT).

CONFORMITY

The CAAA of 1990 established new requirements for transportation plans, programs, and projects. The EPA published a final rule in the November 24, 1993, *Federal Register* (58 *FR* 62188) that finalized the procedures to be followed by the U.S. DOT in determining conformity of transportation plans, programs, and projects. The CAAA emphasized that estimates of emissions from transportation plans and programs must be consistent with the SIP. This integration of transportation and air quality planning is intended to ensure that the emissions associated with transportation improvements are completely accounted for in the SIP.

The conformity regulations require that nonattainment and maintenance areas prepare air quality analyses for the Baseline and Action scenarios for key CAAA years. The present and future Baseline scenarios represent the No-Build condition, which includes all existing roadways and those portions of programmed projects that previously received approval under the NEPA process and will have a traffic impact in the appropriate analysis year. The Action scenario represents the Build condition, which includes the Baseline scenario and those portions of the transportation plan and/or the Transportation Improvement Program (TIP) projects that will be completed by the appropriate analysis year.

The air quality analysis for transportation plans, programs, and projects must be prepared using traffic and emissions data consistent with the data used in the SIP. For example, the mobile source emission factors and traffic data used to calculate the on-road mobile source emissions must be adjusted to represent specific conditions during the ozone season (typically summer) and CO season (typically winter).

The conformity analysis must include Baseline and Action scenarios. The conformity procedures established the Baseline scenario emissions for the key CAAA analysis years. The Action scenario calculates the change in emissions, using the network model for nonexempt projects. The emission factors and traffic data being used in the conformity analysis must be developed using procedures and assumptions consistent with those used in the SIP process and must be from the latest EPA-approved model. These data must be adjusted to represent the ozone and CO seasons, respectively, to ensure appropriate comparisons of the Action scenarios.

The EPA conformity rule contains the criteria for evaluating transportation plans, programs, and projects. This rule requires that the air quality analyses for the transportation plans and/or TIPs evaluate the emission impacts on nonattainment and maintenance areas for ozone and CO. Conformity criteria require that the emissions from the Action scenario should be less than the emissions from the Baseline scenario for the same year and that the Action scenario emissions should be less than the SIP mobile source budget for each analysis year. The requirement for demonstrating that the Action scenario emissions are less than the Baseline scenario emissions is eliminated once the nonattainment area submits an attainment plan. Subsequent conformity analyses need only demonstrate that they are below the SIP mobile source budget.

The air quality analyses for TIPs and/or transportation plans are required to evaluate the effects of the Action scenario versus the Baseline scenario. The following is a description of roadway networks and the traffic-forecasting model-calculated traffic data that should typically be used in a TIP conformity analysis in an ozone nonattainment area:

- The Baseline (1996) scenario includes the existing network conditions and programmed projects that are grandfathered and will be completed (i.e., operational) by 1996.
- The Action (1996) scenario includes the 1996 Baseline scenario and new projects in the 1995 to 1997 TIP (federal and non-federal) that will be completed by 1996.

- The Baseline (1999) scenario includes the 1996 Baseline scenario and programmed projects that are grandfathered and will be completed by 1999.
- The Action (1999) scenario includes the 1999 Baseline scenario and new projects in the 1995 to 1997 TIP that will be completed by 1999. This means it includes the 1999 Baseline scenario, the 1996 Action scenario, and any new projects to be completed by 1999.
- The Attainment Year Baseline scenario includes the 1999 Baseline scenario and programmed projects that are grandfathered and will be completed by the attainment year.
- The Attainment Year Action scenario includes the Attainment Year Baseline scenario and new projects in the 1995 to 1997 TIP that will completed by the attainment year. This means it includes the Attainment Year Baseline scenario, the 1999 Action scenario, and any new projects to be completed by the attainment year.

Grandfathered projects are those projects that were under construction or in the process of right-of-way acquisition on the date that the conformity regulations were published (November 24, 1993) , those projects that come from the first 3 years of the previously conforming transportation plan and/or TIP, and those projects that have completed the NEPA process.

TRANSPORTATION CONTROL MEASURES

TCMs are an important component of an overall strategy for reducing mobile source emissions. Many metropolitan planning organizations (MPOs) rely heavily on emission reductions from TCMs. The CAAA established procedures for integrating TCMs into transportation and environmental planning. TCMs are often focused on the commuting trip because work trips typically have lower vehicle occupancies, occur daily, and tend to be concentrated during the congested peak hours. Experience shows that employers significantly influence how their employees commute; many TCMs are implemented through employer-based commuter programs.

Employer-based programs often attempt to move employees out of drive-alone commuting into ridesharing or alternative transit modes. Employer motivations may include the desire to reduce parking demand, improve corporate image, improve employee morale, or comply with federal, state, or local requirements. Employers often can offer their employees incentives. Specific TCM activities implemented by employers include the distribution of commuter marketing materials; telecommuting programs; flexible, staggered work hours; transit pass and rideshare subsidies; rideshare matching information and services; and bicycle amenities, such as showers, clothing lockers, and safe storage for bikes. The most extensive programs also include parking pricing, fee carpool parking, carpool coordination support, and a guaranteed ride home program. In regions designated as Severe and higher for air quality attainment standards, the CAAA requires that employers institute Employer Commute Option (ECO) programs. ECO programs require employers to reduce single-occupant commuting to meet a specified target for program effectiveness by work site.

Groups of employers are encouraged to form transportation management organizations (TMOs) as an organizational structure for TCM education, service delivery, and marketing. A TMO is a private or public/private group formed to facilitate employer involvement in addressing transportation issues. A TMO provides commuter-related services and information to its members and its respective user groups, which can include employees, visitors, patients, retail customers, and others. Successful TMOs provide a forum for discussion, education, coordination, marketing, and delivery of TCMs, ridesharing matching services, a coordinated guaranteed ride home program, a coordinated bus shuttle system, and/or a forum for developing transportation policy positions.

The CAAA and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) both discuss TCMs as a transportation strategy to be integrated into transportation and environmental planning and programming. ISTEA strives to promote higher system efficiency by improving the effective use and management of the transportation system. The increase in single-occupant vehicle (SOV) use is seen as contradictory to the goals of increased effectiveness that can be achieved through higher vehicle occupancy and increased transit use. Under the ISTEA program of congestion management systems (CMSs), MPOs are required to consider TCMs before looking at expanding capacity for SOVs.

The approval process for funding under the ISTEA Congestion Mitigation and Air Quality (CMAQ) category requires that the emission reduction potential of TCMs be estimated and reductions documented. Many TCMs, such as rideshare programs and parking management programs, are funded by CMAQ. Transportation system management (TSM) programs, such as traffic signal improvements and traffic flow improvements that reduce emissions, are also funded under this category.

ISTEA and CAAA requirements for conformity necessitate that transportation programs be consistent with the mobile source emission reduction strategies of the SIP. This regulatory requirement promotes the integration of TCMs into the mix of air quality control strategies, such as new technologies, growth management, expanded transportation service alternatives, and improved management of the existing transportation system. TCMs should not be seen as an independent solution to air quality and congestion problems but as a component of a comprehensive strategy—if a nonattainment area does not have an approved plan and TIP, TCMs cannot be funded for implementation.

INTERMODAL SURFACE TRANSPORTATION EFFICIENCY ACT

In December of 1991, the President signed ISTEA into law, thereby providing authorizations for highway construction, highway safety, and mass transportation expenditures through fiscal year 1997. The legislation also provided major changes in the makeup of the nation's surface transportation systems, their priority goals, and how they are funded and administered. Major features of ISTEA are as follows:

- The National Highway System (NHS) was established. The NHS incorporates the Interstate Highway System and those roads most important to interstate travel, commerce, and national defense.
- State and local governments were given far greater flexibility in tailoring solutions to their individual transportation problems, while enhanced management and planning systems were established to help them achieve broader consensus. Funds can be used in categories that have been determined by state and local agencies to be important.
- Public participation was re-emphasized as a requirement for all aspects of transportation decision-making, from long-range plans to project selection.
- A new program (CMAQ) was provided for transportation assistance in CAAA nonattainment areas to help achieve the NAAQS.
- Expanded funding was proposed for new technologies, such as intelligent vehicle highway systems and magnetic levitation rail systems, together with increased attention to traditional research and development activities in order to provide better solutions to the nation's future transportation problems.
- Highway traffic safety received more funds, along with new provisions encouraging the use of safety belts and motorcycle helmets.
- Truck regulation uniformity was enhanced by requiring individual state membership in multistate agreements and a single registration system.
- Greater latitude was provided in the use of tolls on federal-aid road, bridge, and tunnel projects, permitting private entities to own toll facilities.

METROPOLITAN PLANNING

Long-range plans are to identify facilities needed for an integrated metropolitan transportation system over a 20-year period. Financial plans should be included showing how the long-range plan can be implemented and funded. In CAAA nonattainment areas, the long-range plans should be coordinated with CAAA requirements for the funding of TCMs.

The following are highlights of the metropolitan planning requirements under ISTEA and the time frames for meeting these requirements:

- The requirements are applicable to all urbanized areas with population greater than 50,000.
- The transportation plan must be updated every 3 years in nonattainment areas and every 5 years in attainment areas.
- The TIP must be prioritized and fiscally constrained.
- Both intermodal and multimodal planning must be included.
- Transportation plans must be analyzed for nonattainment areas.
- Boundaries of the metropolitan planning areas are, at a minimum, the urbanized area for each metropolitan area and the surrounding area forecast to be urbanized in a 20-year planning horizon. In nonattainment areas, the planning boundary must include the entire nonattainment area (except where reduced by joint action of the governor and the MPO).
- Transportation management areas (TMAs) are designated in urbanized areas having a population greater than 200,000. In TMAs, project selection is, for the most part, the responsibility of the appropriate MPO, in consultation with the state. In urbanized areas not designated as TMAs, project selection is the state's responsibility in cooperation with the MPO. In both cases, projects selected must come from an approved metropolitan TIP.
- The planning process in TMAs must be certified every 3 years.
- Simplified planning procedures may be used in attainment areas not designated as TMAs.
- The planning process in nonattainment TMAs prohibits the programming of projects that significantly increase SOV capacity, unless the project results from an approved CMS. Because a CMS was not required before October 1, 1995, an interim approach was provided to permit programming of a project if it resulted from an approved metropolitan planning process and/or NEPA process that met certain criteria proposed by the U.S. DOT. The project analysis would have had to address a full range of multimodal transportation demand management (TDM) options.
- The TIP should be updated at least every 2 years and should cover at least 3 years. It must indicate funds are available to operate and maintain the system.
- If the metropolitan planning process was uncertified for 2 consecutive years after September 30, 1994, then a mandatory sanction was to go into effect on October 1, 1996.

STATEWIDE TRANSPORTATION PLANNING

Under a new provision, states must develop transportation plans and programs for all sections of the state. These must be coordinated with metropolitan planning efforts and fulfill the state's responsibilities under the CAAA. States are required to have a continuous planning process and to develop a statewide transportation improvement program (STIP) for review by the U.S. DOT.

The following list highlights the state planning requirements under ISTEA and time frames for meeting these requirements:

- A statewide planning process must be established that is coordinated with the transportation planning carried out in metropolitan areas and that takes into consideration all modes of transportation.
- Twenty specified factors must be considered by the transportation planning process. Additionally, the statewide planning must coordinate with MPO planning, rural economic growth, tourism development, recreational development, and the concerns of Indian tribal governments having jurisdiction over lands within a state.
- The statewide plan shall be intermodal, cover a planning period of at least 20 years, provide opportunity for public involvement, and require bicycle and pedestrian plans for appropriate areas of the state.
- The STIP must be a staged, multiyear program that includes all federally and non-federally funded projects (highway and transit), including capital and noncapital projects.
- In metropolitan areas, the STIP must be consistent with MPO-generated plans.
- The STIP must cover a period of not less than 3 years and must be submitted for approval at least every 2 years. In nonattainment areas, the state must give priority to TCMs and other projects identified in an approved SIP as having the potential to substantially reduce transportation-related air pollution.
- Approval of the STIP was required by January 1, 1995.

REFERENCES

U. S. Environmental Protection Agency (1991). *Ozone and Carbon Monoxide Areas Designated Nonattainment*, Office of Air Quality Planning and Standards.

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-

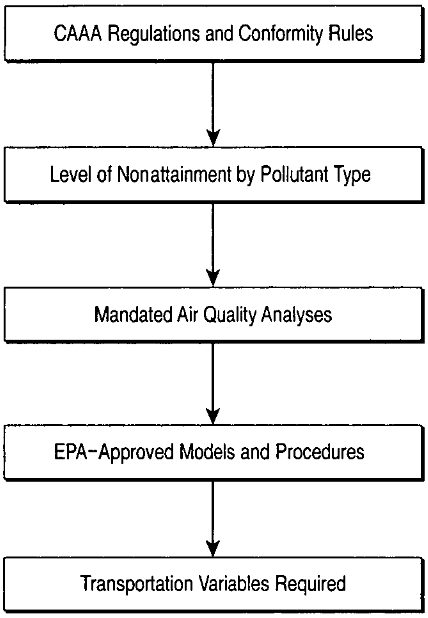

Figure 2-1. Factors determining the variables required.

ing highway network that may experience changes in traffic patterns because of these projects. Mesoscale analyses are most often associated with the assessment of photochemical oxidant effects.

Microscale analyses generally employ a dispersion model to predict concentrations of a pollutant around a specific site, such as an intersection. They are used to estimate the effects on emissions from possible improvements and modifications at that site. Microscale analyses are most often associated with the assessment of effects of CO and particulate matter with sizes less than or equal to 10 microns in aerodynamic diameter (PM-10).

The traffic data and analyses required for each nonattainment class or level are cumulative, that is, those actions required for each lower level of nonattainment are added to those required for a higher level.

TABLE 2-1 CAAA classifications, pollutant types, and attainment deadlines

Pollutant	Classification	Design Value (ppm)	Attainment Deadline
Ozone	Marginal	0.121 up to 0.138	11/15/1993
	Moderate	0.138 up to 0.160	11/15/1996
	Serious	0.160 up to 0.180	11/15/1999
	Severe 1	0.180 up to 0.190	11/15/2005
	Severe 2	0.190 up to 0.280	11/15/2007
	Extreme	0.280 and above	11/15/2010
Carbon Monoxide	Moderate 1	9.1 up to 12.7	12/31/1995
	Moderate 2	12.8 up to 16.4	12/31/1995
	Serious	16.5 and above	12/31/2000
PM-10	Moderate		12/31/1994
	Serious		12/31/2001

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;

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 (>12.7 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 not 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 off set 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 practicably 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.

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:

- 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.

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 NO_x 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 NO_X. 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-

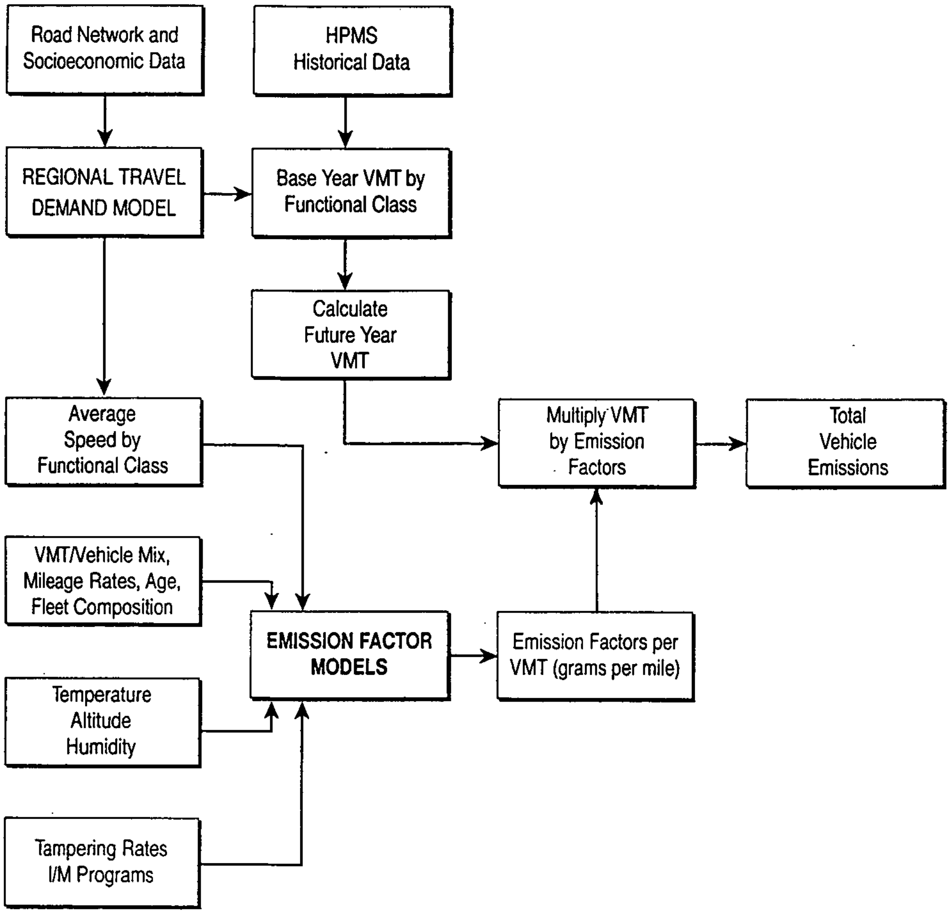

Figure 2-2. Process of mobile source emissions estimation.

ments. Thus, essentially three broad processes are involved as follows:

- 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 NO_x 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_x 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_x 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.

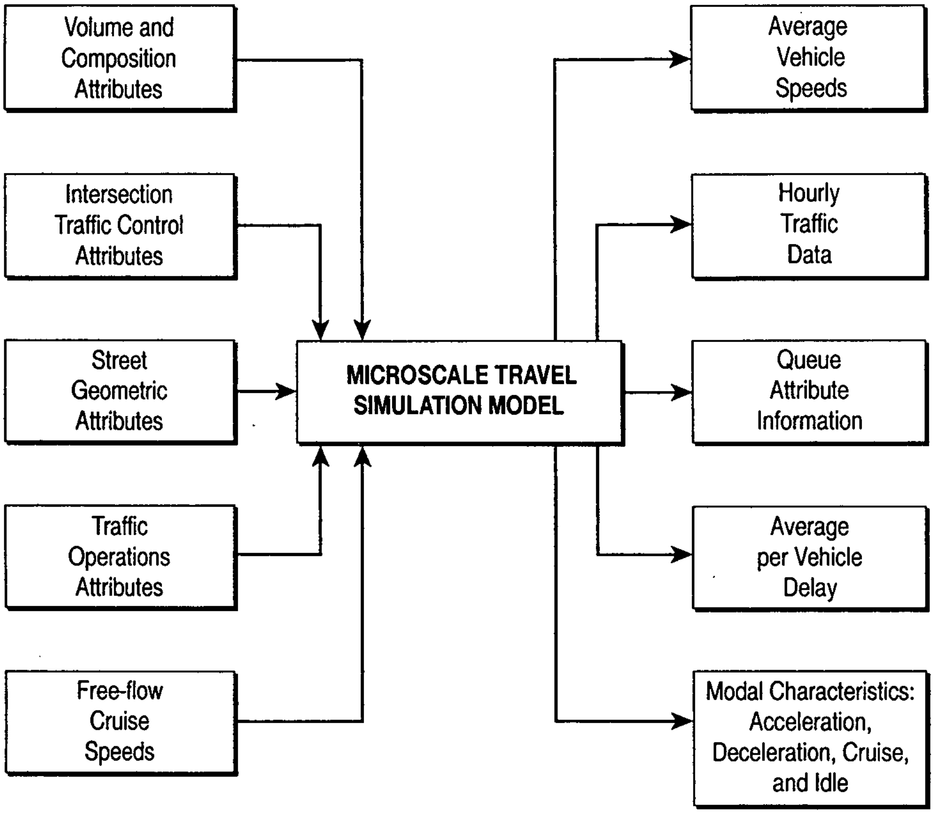

Figure 2-3. Microscale travel estimation.

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,

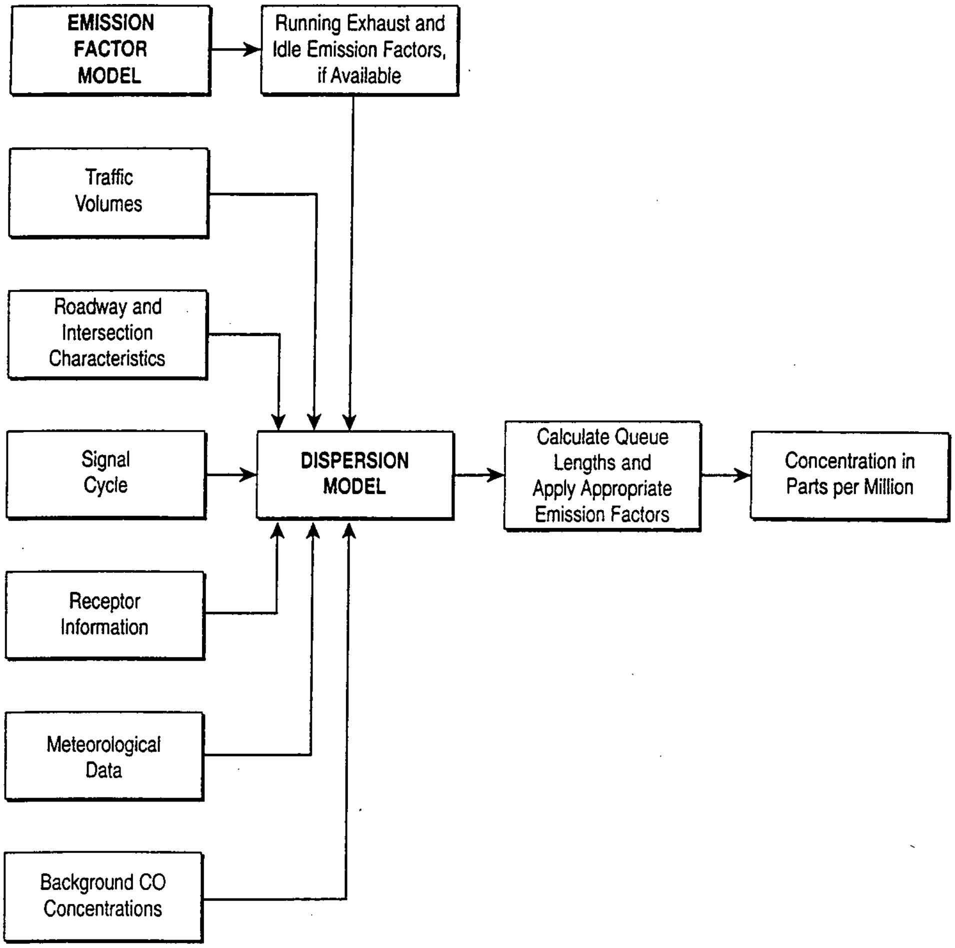

Figure 2-4. Estimating CO concentration.

- 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.

CAL3QHC 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 silt 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 form 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 NO_x increase with higher engine temperatures. In general, NO_x emission rates also increase with increasing speeds. The minimum VOC and CO emission rates are reached at around 48 mph and the minimum NO_x 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 NO_x.

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

$$\text{congested speed} = (\text{free-flow speed})/[1 + 0.15(V/C)^4]$$

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

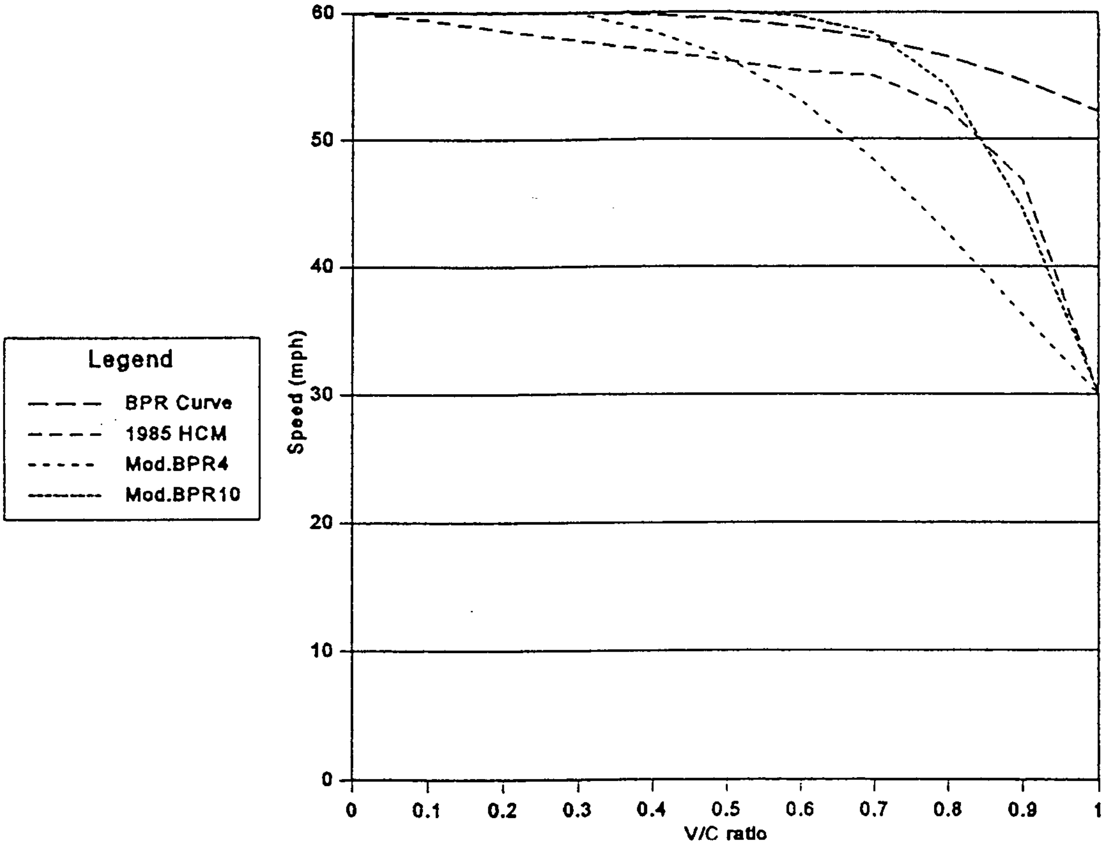

Figure 2-5. Examples of speed-flow curves.

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 "Neilson 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 suburb-to-suburb 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 3 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 inferences 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. LDDT—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 emission 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 nonattainment 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 expected 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 MOBILE5a 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 2-2 Definitions of vehicle type/operating mode combinations

Vehicle Type	Operating Mode (Notation)
Non-catalyst	Cold-start (PCCN)[1]
Catalyst/Non-catalyst	Hot-start (PCHC)[1]
Catalyst	Cold-start (PCCC)[1]
Catalyst/Non-catalyst	Stabilized (1.0 - PCCC - PCHC)

[1] PCCN = 20.6%, PCHC = 27.3% and PCCC = 20.6% for FTP.

TABLE 2-3 Standard splits for specific scenarios

Scenario	PCCN	PCHC	PCCC
FTP Day-Long Regional Analyses and 8-Hour CO Analyses	20.6%	27.3%	20.6%
Peak-Hour Analyses	50%	10%	50%
One Hour Special Event Analyses	100%[1]	0	100%
Hot-Stabilized Analyses (Interstates and Expressways)	0	0	0

[1] 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 Castaline, 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_x. 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 TCMs are being analyzed regarding their effectiveness at reducing 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.

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CHAPTER 3

CURRENT PRACTICE

INTRODUCTION

This chapter presents a review of transportation modeling procedures and data used by MPOs to determine the air quality emissions impact of transportation projects that must meet the requirements of the CAAA. Forty-one MPOs and nine states were contacted during March and April 1994 to assess current practice in air quality transportation modeling (see Figure 3-1). The survey focused on administrative procedures, traffic forecasting methods, speed post-processing, and emissions estimation. Conformity documents and TIPs were also reviewed. The review found that various procedures are in use, but most are variations of the stepwise traffic modeling process. Typically, forecasts of VMT for the urban area (on the basis of the four-step model) are added to VMT in the nonattainment "donut" area surrounding the urbanized area, which is estimated on the basis of sample counts. Speeds are often estimated after traffic assignment, using post-processing methods and congestion-delay curves. Little use of speed feedback in the modeling process was documented, but most regions post-process speeds before estimating emissions. Regional projections for traffic growth are for 10 to 30 percent growth over 10 years. Air pollution levels are expected to fall 15 to 30 percent, but the difference between Build and No-Build options is generally less than 1 percent. Inconsistencies in scale and data sources and uncertainties in estimates were found throughout the process. The review concludes that, although the present traffic forecasting process permits computation of air quality impacts of some transportation actions, it does so in a complex, disjointed, cumbersome way.

METHOD

The CAAA put pressure on states and local governments responsible for transportation planning. These agencies are required to conduct analytical work in support of conformity analysis, VMT reduction, and SIP submittals. Although the cities and states have techniques to analyze transportation-related proposals, these techniques were generally developed in the 1960s and 1970s for evaluating impacts on road users in terms of vehicle operating costs and safety and were not intended to provide a detailed analysis of air quality issues.

An effort was made to identify the current practice of transportation air quality modeling, focusing on how local and state planners deal with model and data requirements and what methods are used to estimate air quality. Information was gathered from telephone surveys of selected cities and states and from review of technical literature. Because time and cost constraints precluded contacting all nonattainment cities, a cross section of 60 cities and state DOTs was selected. Each agency was sent a letter outlining the topics to be discussed and saying that an interviewer would call within several weeks. An interview sheet was then prepared to help channel the discussion to certain subjects and maintain a level of consistency among interviews without overly restricting the answers. Phone interviews were conducted primarily between March 1 and May 2, 1994. Each survey lasted 30 to 45 min. Forty-nine phone interviews were conducted, and one written response was received. Technical reports from each city were also collected and summarized. A separate report (Hartgen, Reser and Martin, 1995) details the findings for each city.

FINDINGS

Reclassification

Of the 41 MPOs contacted, 11 had already applied for air quality reclassification or been reclassified, and 7 were considering it. Most had Marginal or Moderate nonattainment status and improving air quality, but several (e.g., San Diego and Baton Rouge) were rated Serious or higher. As of October 1, 1994, 11 cities originally classified "nonattainment ozone" had been classified "attainment."

Travel Forecasting

The process of travel forecasting and air quality analysis is summarized in Figure 3-2. The heavy-line process flows in Figure 3-2 show the preponderance of practice, while less commonly used procedures are shown with thinner lines. These are not cumulative counts—some areas did not report their procedures in detail—and Figure 3-2 does not track the sequence of procedures used in each city. Figure 3-3 shows the model estimation process in more detail, with approximate average errors (± percent) at various points.

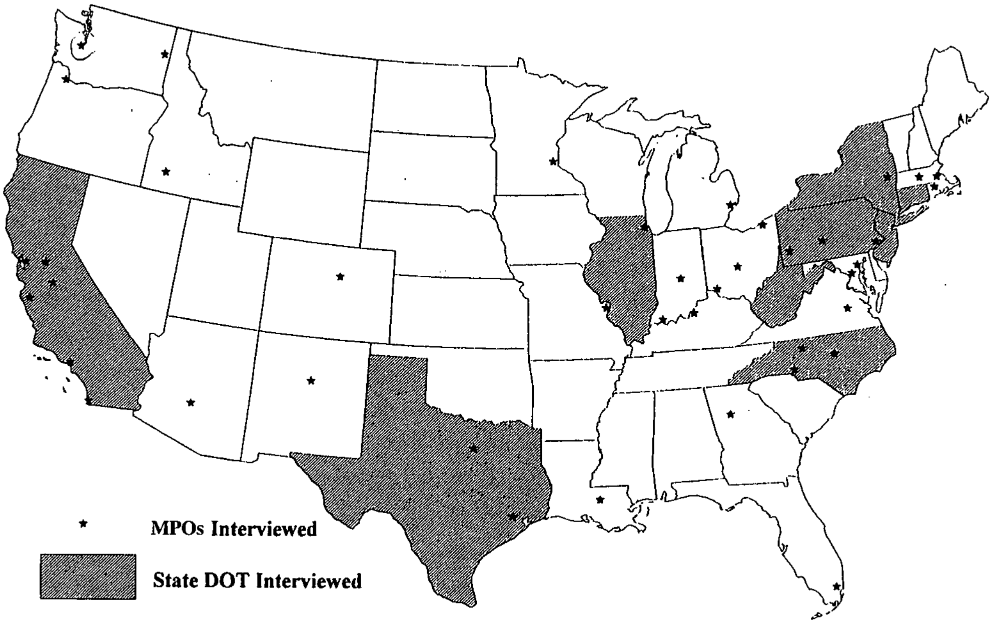


Figure 3-1. MPOs and state DOTs interviewed.

Geographic Area

Three separate circumstances are possible for the geographic area for VMT forecasting as related to that of emissions analysis. In the most common circumstance, the ozone nonattainment area is a group of counties that is substantially larger in area than the "urbanized and future growth" area used for urban transportation planning and travel modeling. This situation forms a "donut" ring around the travel modeling area, within which VMT estimates are required for air quality forecast purposes, but not for urban travel analysis purposes. Of the cities reviewed, most fell into this category, including cities with Severe or higher air quality classifications. A second circumstance has the travel modeling area and the air quality area coterminous. A third case has several air quality districts within one travel modeling area.

Network Detail

Because most metropolitan regions are using travel modeling methods designed for purposes other than air quality analysis, road network detail is generally not adequate for a detailed air quality analysis. In 19 of the 32 cities reporting this information, network detail is limited to collectors and higher classes of roads. Most metropolitan regions are not accounting for local street traffic in any formal way. Of the 41 MPOs contacted, only 13 accounted for local street VMT in some fashion, and only 4 of those (i.e., Minneapolis, Albuquerque, Houston, and Charlotte) included some local streets in the regional network. The others used centroid connectors of fixed length (e.g., Denver and Baltimore) or estimated centroid connector length as a function of zone size (e.g., Boston, Worcester, Stockton, and Seattle) to determine local street VMT. The FHWA-proposed method is to sample local street traffic volume and estimate VMT as the product of average volume and local mileage.

Use of Highway Performance Monitoring System Data

HPMS data were used generally in informal ways, particularly in large metropolitan regions with sophisticated modeling systems. Although more cities reported using HPMS (both informally and as control totals) than did not use it, these cities tended to be smaller metropolitan areas. The use of HPMS for "control totals" is typically done by county and road type. VMT on the HPMS sample segments is summed by county and by road classification (e.g., interstate and principal arterial), then expanded to the category/cell total using the HPMS sample expansion factors. These category/cell totals are then compared with corresponding totals from traffic assignment outputs. The ratios of HPMS to assignment totals, by category, are then used to adjust future traffic forecasts. This procedure is equivalent to a cell-level "pivot point" adjustment or scaling of traffic forecasts. Its original intent was to close the difference between travel model estimates and HPMS estimates for VMT; however, when differences are small, the adjustment is unnecessary, and when large, the adjustment may be inappropriate because it does not also adjust speeds on the network. Several regions using the method observed that the differences are largest for

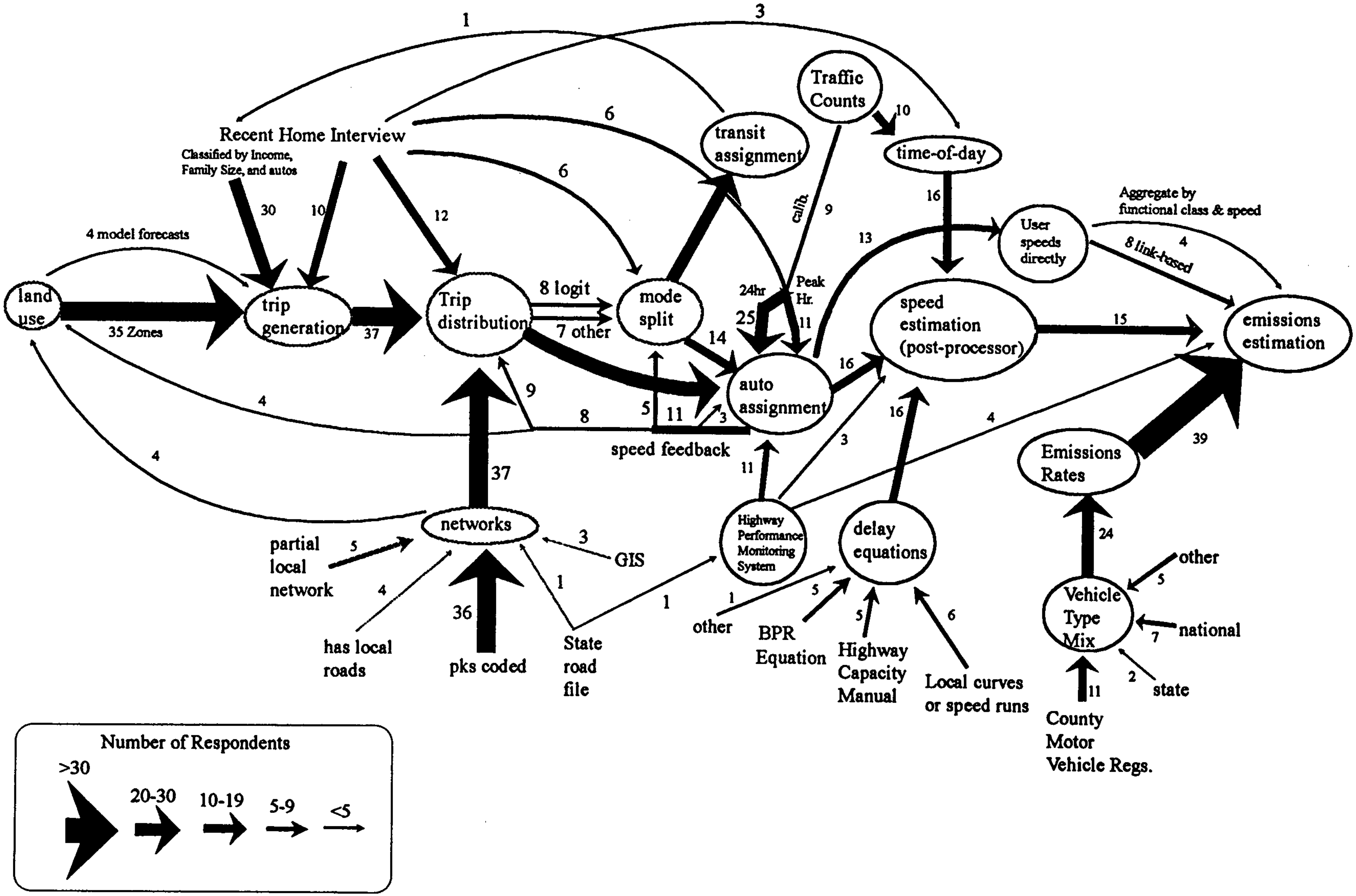


Figure 3-2. Transportation air quality modeling procedures.

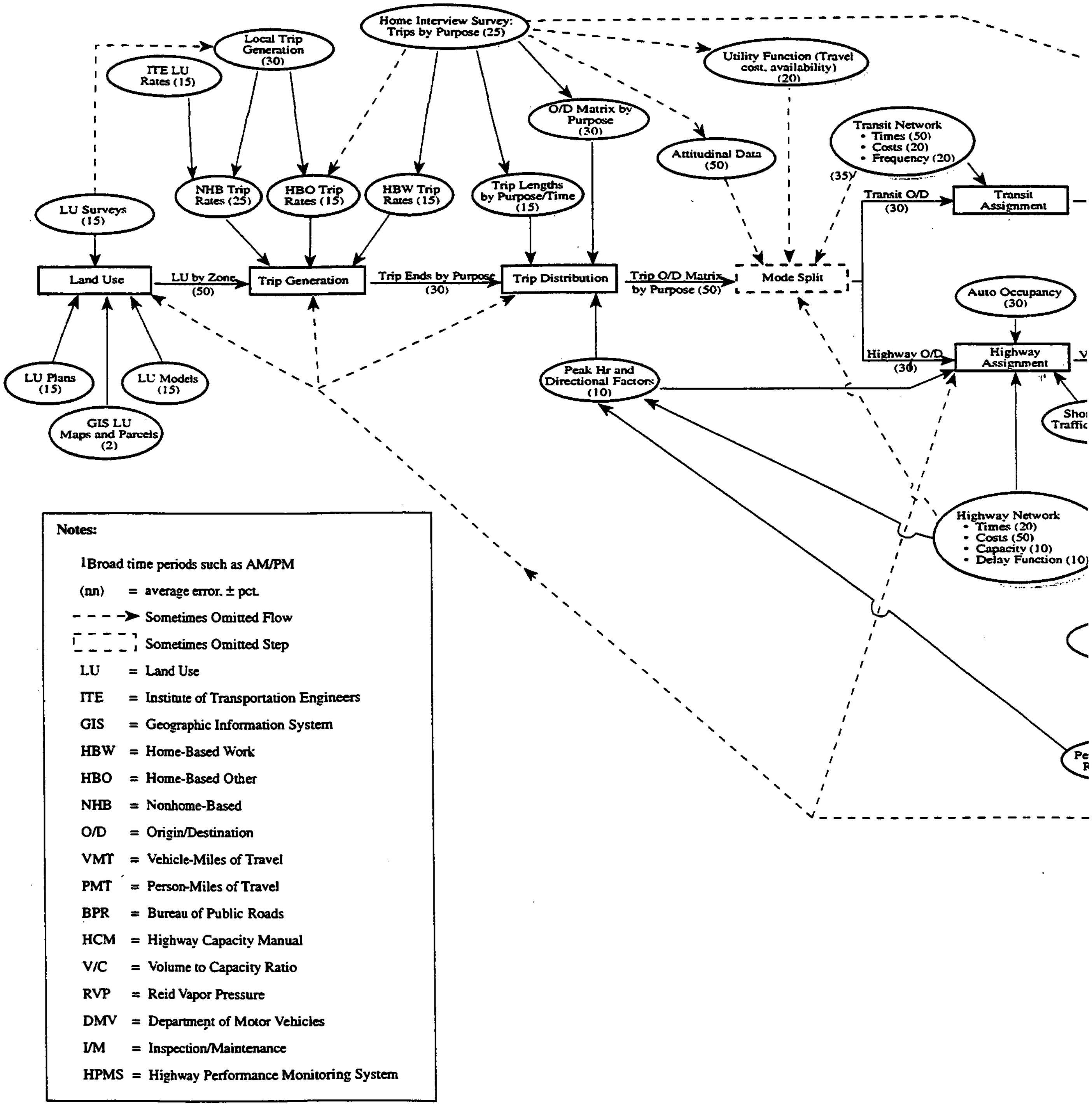
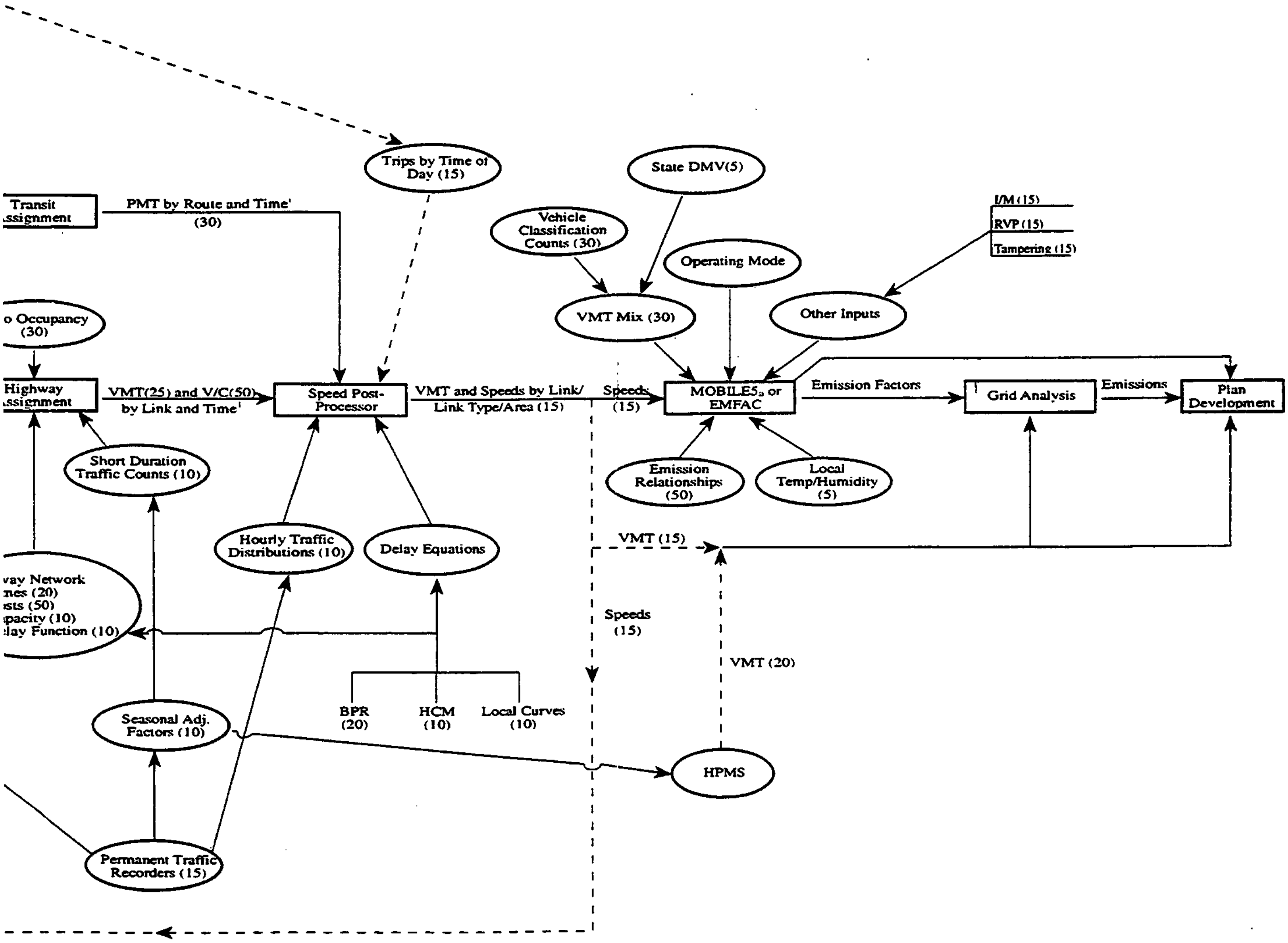


Figure 3-3. Data flow and modeling process for transportation and air quality planning.

small-VMT categories/cells, smallest for major cells. Therefore, the use of the scaling procedure in practice has been quite varied.

In several cases, substantial differences between HPMS statistics and network-based travel model statistics for the base year led to a decision not to use HPMS for scaling purposes. The problem was generally recognized as being one of insufficient HPMS samples of highway sections within metropolitan areas. However, in North Carolina and Pennsylvania, the DOTs used the HPMS estimates directly for county VMT, along with speed data and estimated emissions rates.



Travel Model Validation

Validation procedures (i. e., methods to ensure travel model accuracy in the base year) typically involve input from recent travel surveys and traffic counts. Most cities use a combination of "current" (2 to 5 years old) traffic counts and a home interview travel survey (2 to 10 years old) for model calibration. For cities between the submittal schedules of the CAAA and ongoing model update activities, the most common short-term validation procedure was to use traffic counts and screenline count information. Cities that had conducted recent home interview or external origin-destination surveys took advantage of these sources of data in conjunction with traffic counts (e.g., Los Angeles, Boston, Stockton, Washington, Miami, Pittsburgh, Seattle, Evansville, Harrisburg, Albuquerque, and Denver).

Recent Travel Surveys

Several metropolitan regions have conducted recent travel surveys or have plans for doing so. Most regions mentioned the use of recent (or planned) home interviews and traffic counting efforts, but others also mentioned the use of panels (e.g., Seattle), speed runs (e.g., Boston, San Francisco, and Minneapolis), activity surveys (e.g., Dallas), external travel surveys (e.g., Baton Rouge and Louisville) and on-board transit studies (e.g., San Diego). Without question, the CAAA precipitated another round of travel surveys in many large metropolitan regions.

The de facto standard for travel surveys is now the activity survey. This method of interviewing focuses on the use of activity diaries to record the sequence of activities in the respondent's household, rather than the sequence of trips. Data are typically retrieved via telephone and input directly to computer-aided telephone interview systems, but respondent contact is by mail; no physical visit to the house (home interview) is performed. The method is thought to be more accurate, faster, cheaper, and safer than the older procedure. Most agencies undertaking such surveys hire professional polling firms to design and undertake the effort.

Speed Estimation and Post-Processing

The MPOs use various techniques for estimating congested speeds from traffic assignment data. Overall, about half of the MPOs post-processed speed information in one form or another. Those who do not post-process are of two general groups—those for whom the traffic assignment appears to yield an accurate estimate of congested speeds and those for whom the traffic modeling is less sophisticated or results are available only at the 24-hr level. Post-processing of speed data typically involves estimation of link V/C ratios and average speeds by hour of the day, then computation of weighted average speeds. Cities that have traffic assignment procedures that estimate hourly or time-period traffic typically use congestion-delay curves within the traffic assignment methodology, which allow traffic to be slowed down as volumes increase. These methods produce traffic volumes on highway sections by time of day and their associated speeds.

Speed Feedback in Model Chains

The use of congested travel time (speed) "feedback" in model structure is quite common; however, speed feedbacks are generally limited to congestion loops within the traffic assignment step. Only eight cities reported the use of speed feedback to trip distribution or mode choice (i.e., Boston, San Francisco, Seattle, Chicago, San Diego, Pittsburgh, Los Angeles, and Dallas), and four cities (i.e., Los Angeles, San Francisco, Dallas, and Seattle) reported the use of travel time feedback to land use. More than half of the respondents indicated that they do not use any formal speed feedback mechanism. Some of these cities (e.g., Albuquerque, Washington, Minneapolis, and Louisville) indicated that research was underway to clarify whether such a mechanism would be useful and what its impact would be. San Francisco reported tests that showed only small effects. Another problem is to decide when speed feedback should occur; if done before speed post-processing, speed feedback may be limited in value for air quality analyses.

Emission Estimates

The following three methods are used for arriving at the emissions estimates, after the travel-demand models are completed:

- Direct use of assignment data. Assignment outputs (i.e., VMT and estimated speeds) by link are fed directly into the procedure for emissions estimates; VMT data are aggregated by functional class, and average speeds are estimated for each class of roads. Emission calculation on a link-by-link basis and subsequent aggregation of link-level estimates are less commonly done. This procedure is equivalent to assuming that (1) speed estimates are accurate to within the 5-mph speed classes used for determining emissions rates and (2) average speeds by link are representative of network performance and emissions. Both assumptions are likely to be incorrect, but their effect on emissions estimates is unknown. Consequently, cities using this method are limited to those that have great confidence in congestion-constrained speed estimates (say, by checking speeds with on-street runs) or those that have little congestion and use 24-hr assignments.
- Post-processing of speeds. Alternately, assignment output speeds can be "post-processed," generally with the intent of making them more accurately reflect congested flow. The key step in this activity is the use of speed-flow functions or curves, such as the commonly used BPR equation or *Highway Capacity Manual* curves. Some of the iterative traffic assignment procedures adjust speed, and post-processing provides further refinement of speed.
- HPMS data. A third approach involves using HPMS-based estimates of VMT, augmented with speed data from other sources, to determine emissions. Only a few states or cities are using HPMS data directly for emissions calculations.

Figures 3-4 through 3-6 summarize forecasts of VMT and emissions for selected cities. Emissions reductions from the

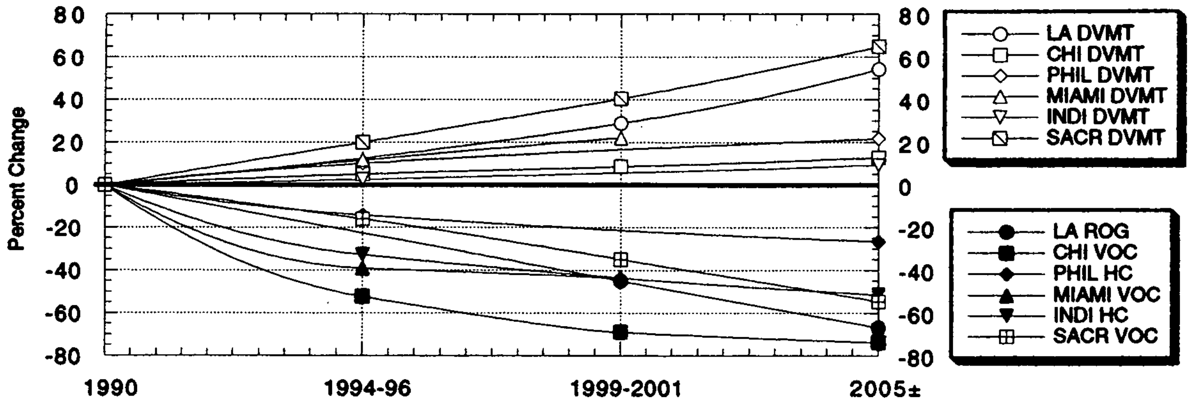


Figure 3-4. Projected changes in HC emissions and daily VMT.

base year of 1990 to 1996 range from -9 to -52 percent, depending on city and pollutant. On the other hand, VMT increases are projected to be 5 to 20 percent. Projected emissions are lower in future years because the future emissions rates in MOBILE5a are lower, as vehicle technology improves. (Of course, VMT increases may offset these reductions.) Emission reductions are large enough to show measurable changes in concentration level, and most respondents forecast changes of more than 15 percent. Therefore, the prospect is for air quality continuing to improve, even over the long term. Results from Build/No-Build model tests reveal minuscule but universal air quality advantages of Build strategies. The Build scenario typically demonstrates an emission savings of less than 1 percent, some as little as 100 lb per day; one city reported estimating a 1-lb reduction 10 years in the future. Such small changes in emissions would be dwarfed by changes in biogenic HC and local daily variations in weather.

Prototype Modeling Systems

Synthesis of current practices reveals three basic approaches for travel modeling for air quality analysis. These are as follows:

- Complex—Sophisticated modeling efforts, typically in larger cities with more extensive air pollution problems,
- Prototype—Modest analytical effort, typically done in medium-sized cities with modest air pollution problems, and
- Simplified—Minimum analytical effort, typical of smaller cities with Marginal or Maintenance air quality status.

Table 3-1 summarizes the features of these typical transportation planning processes. The modeling structure in the complex processes consists of a five-step model chain, supported by recent travel surveys, with each step being sophisticated. Speed feedbacks and land use models are included. In the prototype processes, traditional four-step models are used, supported by traffic counts. Speed feedback is limited to the distribution phase. In the simplified methods, a limited three-step model (dropping mode choice) is combined with counts to produce 24-hr assignments. These different procedures do not seem to show different results in terms of air quality estimates. The results of a model application depend not only on the model's structure but on the data fed into the model. Virtually all reviewed cities showed less than 1 per-

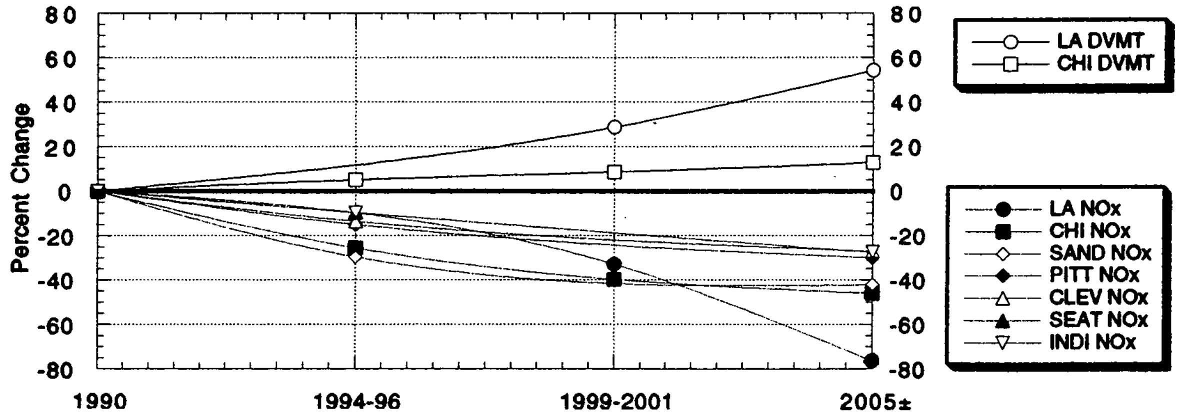


Figure 3-5. Projected changes in emissions of NO_x and daily VMT.

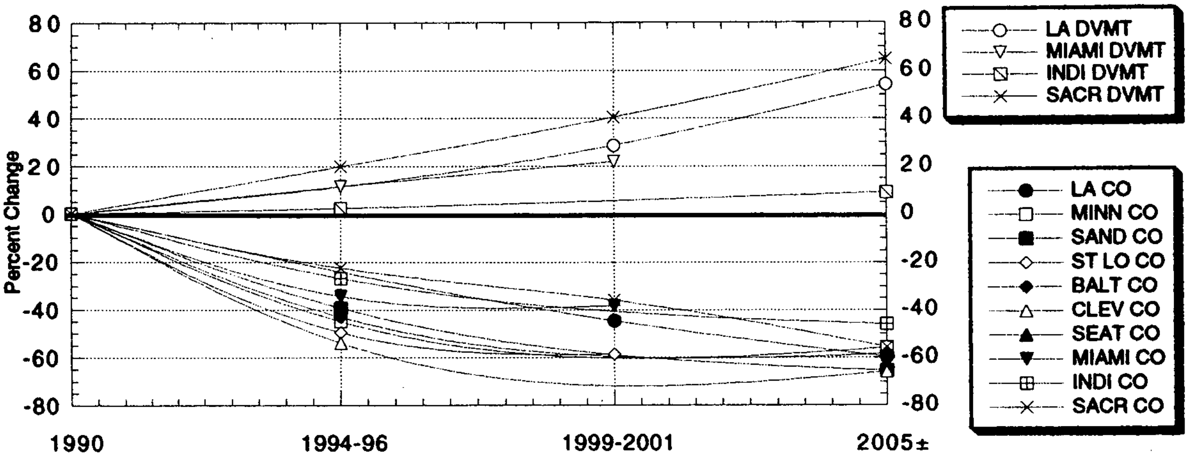


Figure 3-6. Projected changes in CO emissions and daily VMT.

TABLE 3-1 Typical state-of-the-practice models

Dimension	Complex	Prototype	Simplified
City Size	Large	Medium	Small
Ozone status	Serious +	Moderate	Marginal/in attainment
Reclass effort	No	Yes	Yes
Admin. structure	MPO lead	Joint DOT-MPO	DOT lead
SIP status	Rejected/Incomplete	Approved	Approved
VMT Forecasting responsibility	MPO	MPO	MPO-DOT
Geographic area	Urbanized area> AQ area	Donut: Urbanized area smaller than AQ area	UA much smaller than AQ area
Base/Forecast Year	1990/2015	1990/96/2001	1990/96
Model structure	5-step (incl. Land use)	4-step	3-step (no mode split)
Model Packages	TranPlan/UTPS	TranPlan/MINUTP	TranPlan
Network detail	No local streets	No local streets	No local streets
Land use forecast	DRAM/EMPAL	Plan consensus	Plan/none
Trip generation	Specialized 6-8 purposes	3-5 purposes/ X-classification	3 purposes, ITE rates
Distribution	Gravity model	Gravity model.	Gravity model
Mode split	Multi-logit/or specialized	Binary logit/or none	None
Traffic assignment	3-6 time periods	24+1 PK HR	24 hours
K factors data source	Counts/HI	Counts	Rules-of-thumb
HPMS	Not used	Used as check	Used as scale
Validation data	Counts/HI/Ext/OD	Counts/HI	Counts
Recent travel surveys	Yes	No	No
Speed feedbacks	Yes (to distrib, & model choice)	Yes (to distrib)	No
Speed estimation by hour	Local curves	BPR\HCM	No
Summer/winter VMT	Yes/some	-	-
Emissions model	MOBILE5a/California	MOBILE5a	MOBILE5a
Local inputs	Yes	Some	Temp and regulatory only
Build-No Build differences	0.1-1%	0.1-1%	0.1-1%
NOx considerations	Yes/some	-	-
I&M	Yes	Yes	Yes
Oxy Fuels	Yes	-	-
TCMSs	Some	Few	-

cent difference between Build and No-Build forecasts (the primary tests conducted to date), despite 25 to 50 percent increases in VMT, but a 25 to 40 percent reduction in air pollution because of enhanced I/M, reformulated fuels, and other technological innovations. TCMs typically accounted for considerably less than 1 percent of the air pollution reduction.

ASSESSMENT

The following issues were identified in the technical review of the modeling procedures. Some recommendations are offered.

1. Vehicle type and mileage accumulation data. Vehicle type and mileage accumulation data for input to the MOBILE5a model come from many sources. Even areas with sophisticated travel models use national data defaults for these parameters. Use of local data would substantially improve the estimates. (This issue is addressed later in the report.)
2. Summer/winter/weekend traffic adjustments. Surprisingly, few cities reported specific adjustments to traffic forecasts for summer (ozone) or winter (CO) analysis. Improved adjustment procedures are needed.
3. Real-world versus posted speeds. Most cities used posted speed limits, rather than higher real-world driving speeds, in both traffic assignment and emissions analysis.
4. Procedures for VMT estimation in the "donut" area are still in development. The HPMS-based method does not cover local streets. Extra samples could be added to the "donut" area for local streets.
5. Treatment of local street VMT is weak. Most urban travel forecasting models treat local streets in very simplified fashion or do not include them at all. VMT on local streets is typically not modeled. (This issue is addressed later in the report.)
6. Congestion-speed estimation. BPR curves and *Highway Capacity Manual* curves used for post-processing of speeds are unreliable at high V/C ratios and for interrupted flow situations. (This issue is addressed later in the report.)
7. Sources of data for K (design hourly) and D (directional) factors vary widely. Local count data are most commonly used as a source. Accuracy should be increased.
8. Model validation procedures vary widely. No standards are generally available for model calibration or validation.
9. Use and accuracy of HPMS is limited in the larger areas. Only smaller areas, most with limited air quality problems, use HPMS as a check or control. Existing local traffic counts could substitute for HPMS samples, but are not used effectively.
10. Validation using older data is common. Many areas have planned new travel surveys, but recalibration of travel models is planned in only a few areas.
11. Separate data sources for travel and time-of-day data. Travel surveys are used for travel forecasting model development, but time-of-day counts are used for developing diurnal/hourly factors. No time-choice models are in operation.
12. Intersection delay. Most network models include intersection delays, but only as inserts to network travel time.
13. Hot-soak/diurnal/cold-start proportions and trip tracking. Only two cities reported using procedures that account for these in models to produce better information on operating mode fractions. (This topic is examined later in the report.)
14. Variation in speeds within hours or within trip. No cities account for this.
15. Episode (1-day special situation) modeling. No cities do this.
16. Use of land-use models is limited. Most cities do not use land-use models or feedback of speeds to forecast land use.
17. Feedback loops. Feedback in the model chain for speed was limited to trip distribution, with a few cities including mode choice. Most cities did not use feedback of speeds.

In addition to the issues described above, which highlight modeling practices, several other topics need brief discussion. These are as follows:

1. School trips. In most metropolitan areas, school trips constitute 4 to 6 percent of local travel, often 3 to 4 times as much as transit travel. Yet, little attention is paid to such travel, particularly that of teenagers' car use. (Washington D.C. models school trips explicitly.)
2. Interpolation of yearly data. EPA rules allow for interpolation of traffic forecasts to arrive at interim years needed for emissions analysis. Different interpolation procedures (e.g., on the basis of VMT, origin-destination tables, or emissions) are possible.
3. Speeds by vehicle type. No areas estimated speeds separately for different vehicle types, even though wide differences exist in certain road environments.
4. Consistency of scale. Some inconsistencies exist in the scale of analysis between the various tools and input parameters used in transportation/air quality modeling.
5. Cooperation and coordination. Coordination and cooperation among MPOs, DOTs, and state air quality agencies have been generally smooth. In large metropolitan areas, MPOs have taken the lead in estimating air quality and VMT, with the assistance and cooperation of state agencies.

6. Cost of planning. The effort being expended on air quality analysis, particularly on conformity analysis and TCM analysis, appears to have declined recently relative to other transportation planning efforts.
7. Complexity. The effort required to conduct an air quality analysis of Build and No-Build transportation options for several years in the future is not trivial.
8. Accuracy and precision. Estimates of future emissions in metropolitan regions are being reported to 6 or 7 digits and Build/No-Build differences in tenths of tons or less. Precision may have overshadowed accuracy as the criterion for the evaluation of conformity documents.

Although the current analytical system allows for and has allowed for computation of impacts of some transportation actions on air quality, it does so in a complex, disjointed, and cumbersome way.

REFERENCES

Hartgen, D. T., Reser, A. J., and Martin, W. E. (1995). "State of the Practice: Transportation Data and Modeling Procedures for Air Quality Emissions Estimates." Center for Interdisciplinary Transportation Studies, University of North Carolina-Charlotte.

CHAPTER 4

SENSITIVITY ANALYSIS

INTRODUCTION

The CAAA requires a 15 percent reduction in VOC emissions during a 5-year period in many of the ozone nonattainment areas. In addition, most ozone nonattainment areas must use the UAM to predict additional emission reductions that will be needed to attain the NAAQS for ozone. These future emission limits define annual emission budgets that apply to stationary and mobile sources. When the UAM is run, it must first be run for a baseline case that includes modeling of the historical events when the ozone standard was exceeded. This modeling requires what the EPA refers to as "day specific" emission inventories. For example, if the ozone standard was exceeded on a Wednesday in June 1990, then mobile source emissions must be estimated for a Wednesday in June 1990. Furthermore, for this example, emissions must be estimated for some future year on a Wednesday in June as part of the compliance demonstration.

These modeling-related requirements demand and assume considerable accuracy in the ability to determine mobile source emissions. The "15 percent requirement" implies a 3 percent per year change in the annual emissions budget and requires a progress demonstration every 3 years showing that mobile source emissions have not jeopardized the planned 3 percent per year reduction. Furthermore, day-specific emission inventories require the ability to estimate mobile source parameters with more accuracy than can be obtained using "average day" statistics. The requirements of the EPA seem to assume the ability to estimate the necessary traffic parameters with sufficient accuracy to produce emission estimates accurate within a few percent. However, an accuracy of ±15 to 30 percent in the estimates of CO, VOCs, and NO_x emissions is the best that can be achieved with state-of-the-art methods for estimating the travel-related parameters needed by the MOBILE5a model. The CAAA requires that detailed plans be developed and approved by the EPA that demonstrate increments of emissions reduction that are statistically difficult, if not impossible, to prove.

APPROACH

A traditional sensitivity analysis was performed to reveal how sharply emission factors change in response to different levels of specific input parameters. Different sets of inputs were defined, and multiple runs of MOBILE5a were made to produce emission rates for comparison. The results are summarized in bar charts and line graphs. Tables have been prepared showing how much of a change in each input parameter produces a 10 percent change in the composite emission factors for the fleet for CO, VOCs, and NO_x.

First, the research team established a set of base case conditions (or defaults) that were held constant while each of the other input parameters was varied, one at a time. The base case was designed to represent a near future (1996) vehicle fleet with 7.8 Reid vapor pressure (RVP) fuel in a low-altitude (500 feet above sea level) city without I/M or antitampering programs (ATP). Base case emissions were for 75°F, with a 65° low and an 85° high temperature for the day. The base case speed was set equal to the FTP average speed of 19.6 mph. The operating mode VMT mix was set to the FTP default values of 20.6 percent cold-start, 27.3 percent hot-start, and 52.1 percent hot-stabilized engine operations. National default values in the MOBILE5a program for vehicle type mix, vehicle registration (reflecting vehicle age mix), and mileage accumulation rates were used. For the base case, additional correction factors for air conditioning, trailer towing, extra loads, and humidity were not used. The results of the sensitivity analysis are presented separately for each travel-related input parameter. The likely error or uncertainty for each travel-related parameter is also discussed.

SPEED

In the analysis, multiple runs of MOBILE5a were made with increasing speed from 2.5 to 65 mph at 5 mph intervals. Emissions of CO, VOCs, and NO_x were calculated in grams per mile and grams per minute and are plotted versus speed in Figures 4-1 through 4-6. The simplest relationships between vehicle emissions and speed are shown in Figures 4-4 through 4-6. Emissions in *grams per minute* of all three pollutants are lowest when the engine is idling; the emissions increase with speed. The incremental rate of increasing emissions is greatest for NO_x and least for CO. The highest emission rates from the engine occur at the highest speeds (65 mph is the highest speed in MOBILE5a) when engine revolutions per minute (RPM) and loads are greatest. When emissions are reported in *grams per mile* of travel, the curves appear as shown in Figures 4-1 through 4-3. Because a car travels zero miles when idling, emissions reported in grams per mile approach infinity at zero speed. This effect causes all three curves to show relatively high emission rates for low speeds, especially below 10 mph. Emissions in grams per

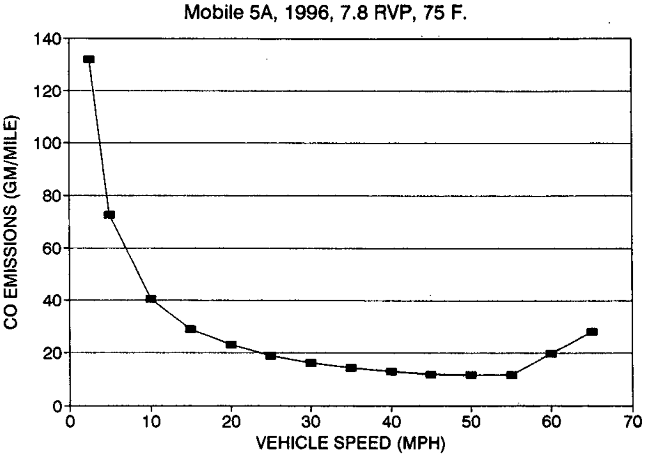


Figure 4-1. CO emissions (gm/mile) vs. vehicle speed.

mile tend to be lowest in the 30 to 45 mph range, then increase again for speeds greater than 55 mph.

Table 4-1 presents a summary of calculated emission factors for three speeds. It also shows the slope of the emissions curve for the entire fleet (i.e., all vehicles) at these three speeds. This slope is used to calculate the change in speed required to produce a 10 percent change in emissions. The steeper the slope, the more sensitive is the model to changes in this parameter. The slope is treated as a measure of the accuracy required in vehicle speed inputs to the MOBILE5a model to prevent a 10 percent error in the estimate of emissions. As shown in Table 4-1, the steepest slope in the emissions curve for CO with respect to speed is around 60 mph. At this speed, an error of 1.2 mph in the speed input yields a 10 percent error in the CO emission factor. At 20 mph, an error of 2.3 mph will produce a 10 percent error in CO emissions, while a 2.7 mph error will produce a 10 percent error in VOC emissions. NO_x emissions are less sensitive to speed. At 20 mph a 10 mph error in speed inputs yields a 10 percent error in the NO_x emission factor.

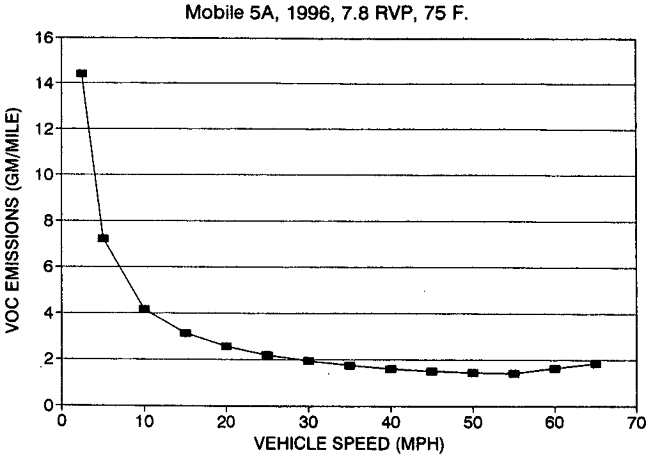


Figure 4-2. VOC emissions (gm/mile) vs. vehicle speed.

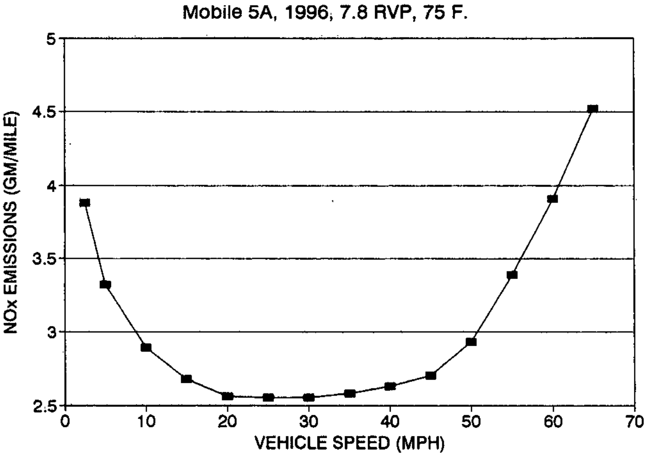


Figure 4-3. NO_x emissions (gm/mile) vs. vehicle speed.

Walker and Peng (1995) investigated errors in vehicle speed estimates for the Delaware Valley area. They reported average errors between measured and modeled speeds of 37.8 percent when using posted speed limits as the basis for speed estimates. Errors were reduced to 12 to 13 percent when speeds were estimated in the model on the basis of V/C ratios and the Evans Algorithm. Chapter 5 of this report presents an analysis of speed data from Orlando and Denver freeways. Under unsaturated conditions, an average speed of 55 mph was calculated with a coefficient of variation of 5.8 percent. Under saturated conditions, an average speed of 16 mph was calculated with a coefficient of variation of 30 percent. This yields an average error for freeways of ±3 to 5 mph. Stopher (1995) summarized the above findings in terms of expected accuracy under "best case" conditions when the best available traffic data and most sophisticated modeling techniques are used versus the "average expectation for an MPO." According to Stopher, in the best case, an error of ±5 mph in the average vehicle speed and ±5 percent in VMT might be expected. For the average expectation for an MPO,

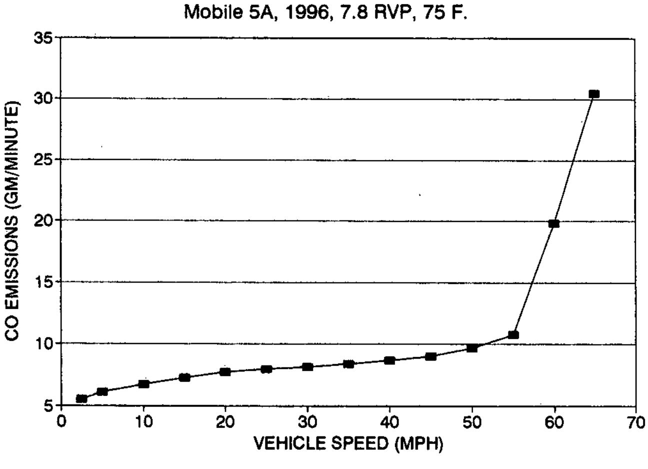


Figure 4-4. CO emissions (gm/minute) vs. vehicle speed.

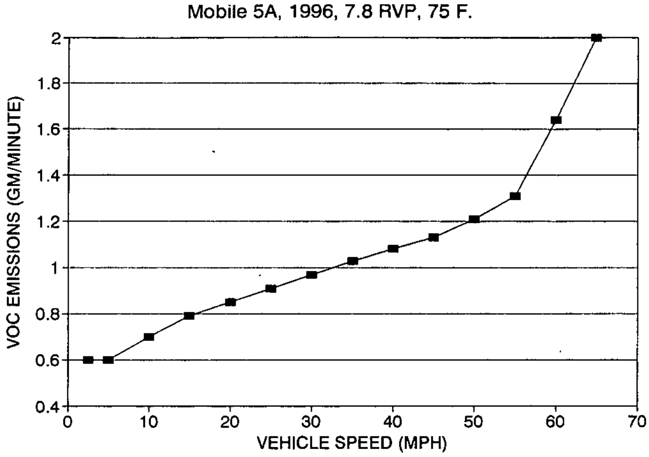


Figure 4-5. VOC emissions (gm/minute) vs. vehicle speed.

the error increases to ±15 mph for estimated speeds on all facility types and ±10 percent for VMT. Furthermore, speed estimate errors are probably lowest for interstates and freeways and greater for other arterials and collectors.

OPERATING MODE AND TEMPERATURE

The FTP employs three vehicle operating modes during the testing of cars and light trucks—cold start, hot start, and hot stabilized. Emissions of CO and VOCs tend to be highest during cold-start operations when the engine and catalytic converters have not warmed up sufficiently. Hot starts cause some increase in emissions, but not as much as cold starts. Cold-start emissions are measured during the first 505 sec (8.4 min) of vehicle operation. Hot-stabilized emissions are measured during the remaining portion of FTP, after which the engine is shut off and allowed to cool a little. Then the engine is restarted for measuring hot-start emissions during a 505-sec period. Figures 4-7 through 4-9 present the results of the sensitivity analysis for the three operating modes for the three pollutants for three different ambient temperatures. The bar charts are labeled using the same three-number scheme (e.g., 100/0/100) used in the MOBILE5a model where the first and third numbers are the percent cold starts and the second number is the percent hot starts. The percent hot stabilized must be calculated as 100 minus the sum of the other two numbers. A label of "0/0/0" means 100 percent hot-stabilized operation.

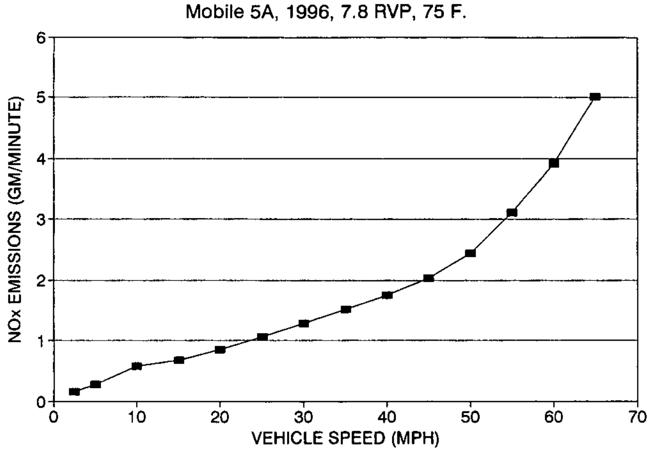


Figure 4-6. NO_x emissions (gm/minute) vs. vehicle speed.

As the figures show, the greatest difference in emissions because of operating mode is for VOCs during cold (32°F) conditions when cold-start emission rates are 5 times higher than hot-stabilized operations. Similarly, CO emissions are 3 times higher during cold-start operations at 32°F than during hot-stabilized operations. During warmer weather (75–95°F) cold-start emissions of VOCs and CO are about 2 times higher than hot-stabilized emissions. NO_x emissions are much less sensitive to changes in operating mode.

Tables 4-2 and 4-3 show the incremental changes in cold-start and hot-start percent operations that would yield a 10 percent change in emissions from the base case FTP default of 20.6/27.3/20.6. The most sensitive case is for VOCs at 32°F when a 4.4 percent change in cold starts would yield a 10 percent change in the VOC emission factor for all vehicles. Similarly, at 32°F, a 6.6 percent change in cold starts would cause a 10 percent change in CO emissions. NO_x is not very sensitive to operating mode. The most sensitive case looked at for NO_x would require a 36 percent change in the percent of cold starts to produce a change of 10 percent in the emission factors. Hot starts showed less sensitivity—a 30 percent or greater change in hot starts was required in order to produce a 10 percent change in the average emission factor for all vehicles.

Actual on-road cold-start fractions vary for different facility types, times of day, and proximity to trip origin. Measurements of trip duration distribution in Seattle and Baltimore as reported by Kishan et al. (1993) tend to support the average cold-start VMT percentage of about 20 percent. An evaluation of 9,121 trips showed a median trip duration of about 7 min, with a 60:40 ratio of hot starts to cold starts (on the basis of soak times of <1 or >1 hr, respectively). Venigalla et al. (1995) evaluated NPTS data and concluded that, nationally, 31.2 percent of VMT occurs in the cold-start mode. Differences show up more by facility type. Estimates made by Benson (1988) and Brodtman and Fuca (1984) and summarized by Miller et al. (1991) show cold-start fractions ranging from 5 percent on interstates to 64 percent on local streets during the morning peak hour. Estimating the standard deviation by dividing the range by 6 yields an estimate of the typical variability in cold-start percentage of ±10 percent (i.e., when facility type is not taken into account).

VEHICLE TYPE

The MOBILE5a model provides emission factors for eight different types of vehicles. These are

- LDGV—light-duty gasoline vehicles (passenger cars);
- LDGT1—light-duty gasoline trucks (pickup trucks and vans less than 6,000 lbs. gross weight);

TABLE 4-1 Sensitivity of MOBILE5a emission factors to changes in average vehicle speed

Pollutant	Speed (mph)	Emission Factor (gm/mi)	Slope (gm/mi/mph)	Speed Change Causing ±10% Change[1] (mph)
CO	20	23.12	1.0	2.3
CO	40	13	.23	5.6
CO	60	19.8	1.7	1.2
VOC	20	2.56	.095	2.7
VOC	40	1.62	.025	6.5
VOC	60	1.64	.042	3.9
NOx	20	2.56	.025	10
NOx	40	2.63	.012	22
NOx	60	3.91	.113	3.5

[1] The last column presents the error in the speed input to the model (in mph) that causes a 10% change in the calculated emission factor.

Note: All MOBILE5a runs were for 75°F, low altitude, 7.3 RVP, no I/M, a default vehicle registration and mileage accumulation. Emission factors shown are the composite values for the whole fleet.

- LDGT2—light-duty gasoline trucks up to 8,500 lb gross weight;
- HDGV—heavy-duty gasoline vehicles greater than 8,500 lb gross weight;
- LDDV—light-duty diesel vehicles;
- LDDT—light-duty diesel trucks
- HDDV—heavy-duty diesel trucks (mostly 18 wheelers); and
- MC—motorcycles.

Figures 4-10 through 4-12 show the emission factors calculated by the MOBILE5a model for each vehicle type for three pollutants at three temperatures. (The figures also show a bar labeled "all," which is the composite emissions factor for the whole fleet.)

As shown in Figures 4-10 through 4-12, HDGVs emit more CO and VOCs than any other vehicle type. HDGV emission factors for CO are 4 to 6 times higher than LDGV emissions, while VOC emissions are 2 to 3 times higher, depending on the temperature. For NO_x emissions, the HDDV vehicle category is highest with NO_x emission factors that are 6 to 7 times higher than for LDGVs.

Table 4-4 shows the estimates of the change in vehicle type percentage that will yield a 10 percent change in the composite emissions factors for the fleet. To calculate the change in fleetwide emissions, when the LDGV category was increased, all other categories were decreased proportionally. When other vehicle categories were increased, the LDGV category was decreased an equal amount. The most sensitive parameter is the HDDV effect on NO_x emissions. A change of 2.1 percent

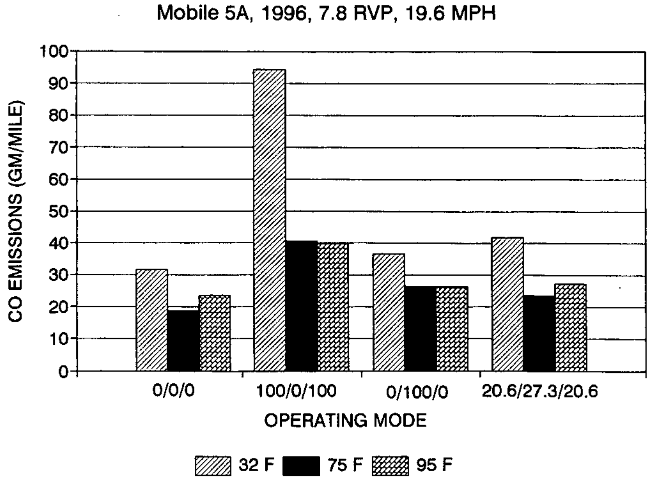


Figure 4-7. CO emissions (gm/mile) vs. operating mode.

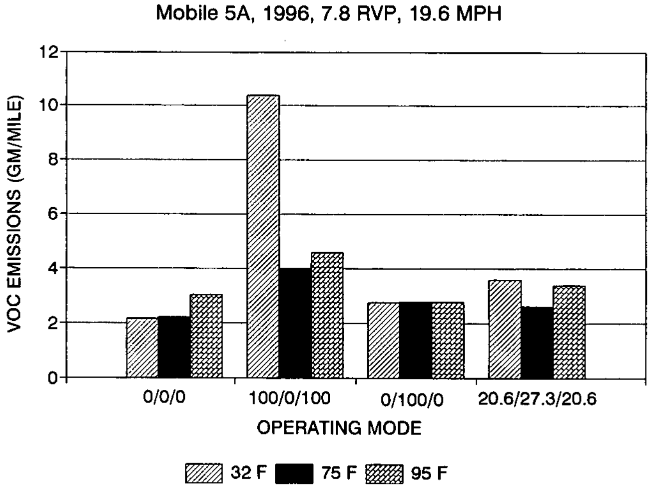


Figure 4-8. VOC emissions (gm/mile) vs. operating mode.

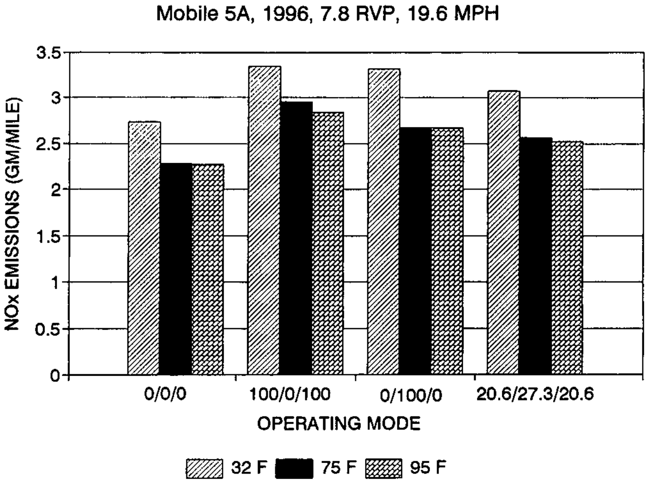


Figure 4-9. NO_x emissions (gm/mile) vs. operating mode.

in the HDDV VMT would cause a 10 percent change in the NO_x emissions factor. The CO emission factor is affected more by changes in HDGV fraction. A 2.8 percent change in HDGV fraction of the fleet changes the composite fleet emission factor by 10 percent. A 4.8 percent change in HDGV causes a 10 percent change in VOC emissions.

Chapter 5 presents the findings of an investigation of possible errors in vehicle mix estimates. The analysis involves 477 days of daily vehicle classification data from urban interstates, arterials, and collectors submitted to the FHWA by 22 states, collected at 320 different sites, as part of FHWA's Annual Truck Weight Study. For urban interstates, the FHWA calculated an average of 74.2 percent LDGVs, with a standard deviation of 11.3 percent. HDGVs averaged 1.8 percent, with a standard deviation of 0.8 percent. HDDVs averaged 10.6 percent, with a standard deviation of 7.2 percent. HDDVs showed the largest variability across facility types averaging 10.6 percent on interstates, 4.6 percent on principal arterials, and 2.6 percent on minor arterials. The standard deviation of HDDVs for all facility types combined was 6.2 percent. This can be viewed as an estimate of the "likely" error in HDDV mix when facility type is not considered. When facility type is considered, the lowest variation of HDDV percentage was found for minor arterials, for which the standard deviation was 2.6 percent.

VEHICLE AGE MIX

Vehicle age influences air pollution emissions for two reasons: (1) new cars emit less pollution than old cars because of design changes and improvements in air pollution control devices, especially catalytic converters; and (2) as a car ages, its air pollution control equipment deteriorates causing it to increase emissions. New model year vehicles typically emit 96 percent less CO and VOCs and 75 percent less NO_x than pre-1968 uncontrolled vehicles. Deterioration rates used in the MOBILE5a model are quite high, with emissions typically increasing by more than 50 percent after the first year of operation. After 4 years of operation (or 50,000 miles) CO emissions are roughly 10 times higher, VOC emissions are about 4 times higher, and NO_x emissions are about 2 times higher than when the car was new. The faster old cars are replaced with new cars, the lower the emissions are for the whole fleet.

In the MOBILE5a model, the total vehicle fleet is made up of vehicle ages of from less than 1 year to greater than 25 years old. Vehicle age mix refers to the percentage of each model year that makes up the current fleet. Figure 4-13 shows the default vehicle age mix in the MOBILE5a model, which is based on national vehicle sales and registration data. The default vehicle age mix has 53.5 percent of vehicles less than 7 years old, with an average replacement rate (i.e., new car purchases each year) equal to about 8 percent of the existing fleet per year. After 7 years, vehicles tend to be retired (taken out of service) at a rate of roughly 15 percent per year. Only 1 percent of the fleet is older than 25 years. One other feature of the default vehicle age mix is that it is for January, so the latest model year vehicle constitutes only 5 percent of the fleet as

TABLE 4-2 Sensitivity of MOBILE5a emission factors to changes in percent of cold starts

Pollutant	Temperature (°F)	Emission Factor for 20.6% Cold Starts (gm/mi)	Slope (gm/mile/%)	% Change in Cold Starts Causing ±10% Change in Emission Rate
CO	32	41.84	.63	6.6
CO	75	23.51	.22	11
CO	95	27.25	.16	17
VOC	32	3.59	.082	4.4
VOC	75	2.59	.018	14
VOC	95	3.39	.016	21
NOx	32	3.07	.006	51
NOx	75	2.56	.007	36
NOx	95	2.52	.006	42

TABLE 4-3 Sensitivity of MOBILE5a emission factors to changes in percent of hot starts

Pollutant	Temperature (°F)	Emission Factor for 27.3% Hot Starts (gm/mi)	Slope (gm/mile/%)	% Change in Hot Starts Causing ±10% Change in Emission Rate
CO	32	41.84	.049	85
CO	75	23.51	.077	30
CO	95	27.25	.028	97
VOC	32	3.59	.0056	64
VOC	75	2.59	.0055	47
VOC	95	3.39	.0027	125
NOx	32	3.07	.0059	52
NOx	75	2.56	.0039	66
NOx	95	2.52	.004	63

there have only been 4 or 5 months of the latest model vehicle sales by January (new models usually come out in September).

Also shown in Figure 4-13 is a hypothetical vehicle age distribution that follows an 8.3 percent vehicle replacement rate for 7 years (with 60 percent of first-year sales occurring by January), followed by a 15 percent retirement rate each year. The hypothetical curve is presented for purposes of comparison to the default age mix. The default age mix of MOBILE5a shows peaks (at year 12) and valleys (at year 9) which reflect actual years of high and low vehicle sales, respectively. Figure 4-14 shows a plot of the U.S. vehicle sales (Motor Vehicle Manufacturers Association, 1991) each year from 1978 to 1990 expressed as a percentage of the existing fleet (on the basis of total vehicle registration nationally). Variations in vehicle sales reflect buyer behavior and the condition of the economy. 1978 was a good year for vehicle sales with new car sales equal to almost 10 percent of the existing fleet. 1982 and 1990 were years of relatively poor vehicle sales with new car purchases equal to just over 6 percent of the existing fleet.

To investigate the effect of a change in vehicle age mix on emissions, two hypothetical age distributions were developed, one with more new cars (on the basis of a 15 percent per year replacement rate) and one with more old cars (on the basis of a 5 percent per year replacement rate) compared to the 8.3 percent per year replacement rate in the default vehicle mix in the MOBILE5a model. The default vehicle mix has a median vehicle age of 6.5 years. The two hypothetical age distributions have median vehicle ages of 3.5 years and 9.5 years, respectively. The default age mix and the two hypothetical age mixes are presented in detail in Table 4-5.

The MOBILE5a model was run for all three age mixes. The same hypothetical age mixes were entered for all vehicle types and the results compared. Table 4-6 shows the calculated emission factors for LDGVs, LDGT2s, and "all" vehicles (equal to the composite emission factor for the whole fleet). The final two columns of the table give the average slope, which is equal to the percent change in the emission factor per year of change in median vehicle age. As shown in

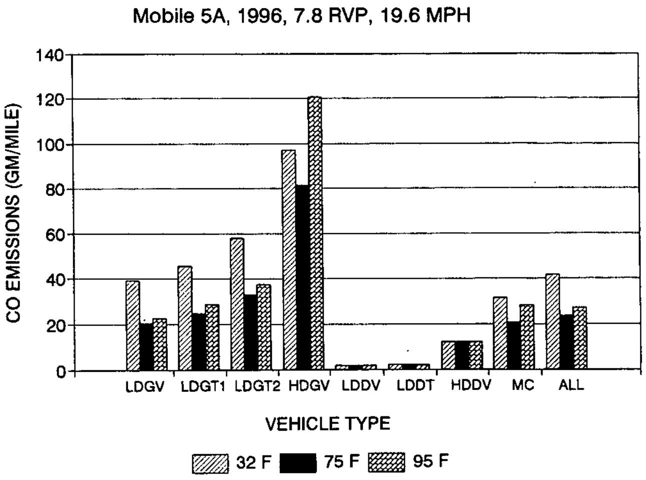


Figure 4-10. CO emissions (gm/mile) vs. vehicle type.

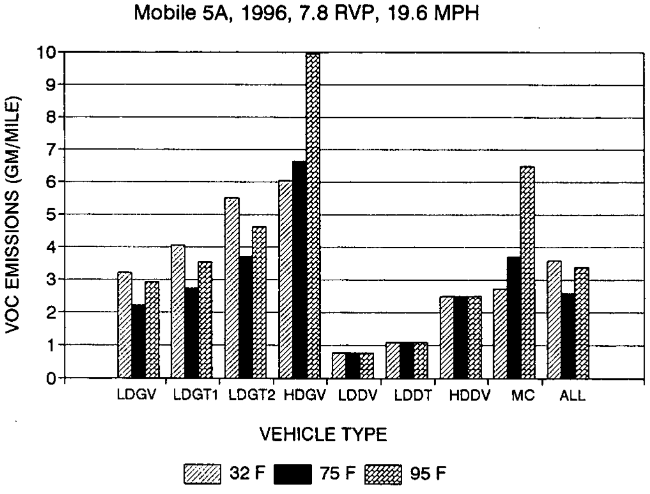


Figure 4-11. VOC emissions (gm/mile) vs. vehicle type.

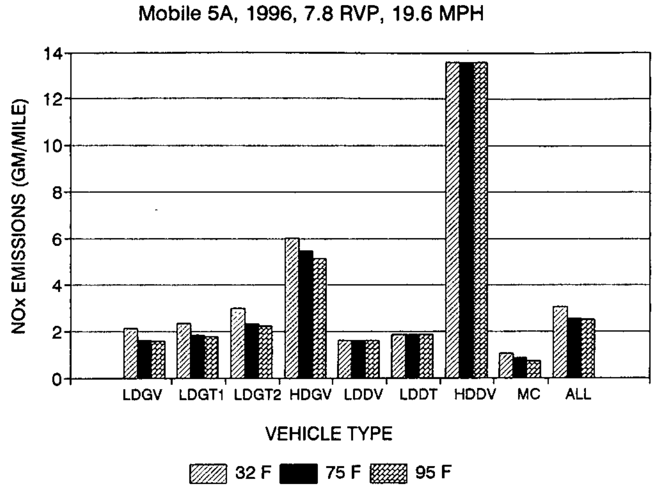


Figure 4-12. NO_x emissions (gm/mile) vs. vehicle type.

Table 4-6, the CO emission factor for LDGV increases 11.7 percent for a 1-year increase in the median vehicle age. The same emission factor decreases 12.9 percent for a 1-year decrease in median vehicle age. Similarly VOC and NO_x emission factors for LDGVs vary from 8.8 percent to 11.4 percent per year for a 1-year change in median vehicle age.

Vehicle age distributions vary from state to state and city to city on the basis of climate (e.g., cars survive longer in hot and dry climates than in cold and wet climates where roads are salted in winter) and economic factors. R. L. Polk and Co. (1992) published data showing that, nationally, the median vehicle age for cars and trucks combined has varied from 4.9 to 7.0 years between 1970 and 1991. Statewide data for Louisiana for 1990, obtained from Stopher (1995), showed an LDGV median age of 9 years. The Louisiana data reflect a lower rate of replacing old cars with new ones equal to 5 to 6 percent of the fleet replaced each year. County-level vehicle registration data for 1990 for New Castle County, DE, was obtained from Wholley (1995). These data show that New Castle County has a much higher rate of purchasing new cars with an annual replacement rate of 8 to 9 percent new cars per year and a median fleet age of 5.9 years. In wealthier neighborhoods, the median vehicle age could be as little as 2 to 3 years.

Mileage accumulation rates for different states might be used as a surrogate for differences in age distribution. States such as Arkansas, which report more than 14,000 miles driven per vehicle per year (FHWA, 1992), accumulate 50,000 miles on a vehicle in an average of 3.5 years; states such as Alaska, which report less than 8,500 miles per vehicle per year, may take 6 years to accumulate 50,000 miles on a vehicle. Higher mileage accumulation rates, as well as older vehicle fleets, both cause higher emission rates. The

TABLE 4-4 Sensitivity of MOBILE5a emission factors to changes in the vehicle type

Pollutant	Vehicle Type	Default Vehicle Percent	Emission Factor (gm/mile)	Slope[1] (gm/mile/%)	% Change in Fleet Percentage of this Vehicle Type Causing ±10% Change in Emission Rate
CO	ALL	100	27.25		
CO	LDGV	63	22.52	-.128	21.3
CO	LDGT2	8.4	37.45	.149	18.3
CO	HDGV	3.1	120.8	.98	2.8
CO	HDDV	6.2	12.16	-.104	26.2
VOC	ALL	100	3.39		
VOC	LDGV	63	2.93	-.012	28.2
VOC	LDGT2	8.4	4.63	.017	19.9
VOC	HDGV	3.1	9.95	.070	4.8
VOC	HDDV	6.2	2.49	-.004	85
NOx	ALL	100	2.52		
NOx	LDGV	63	1.58	-.025	10.1
NOx	LDGT2	8.4	2.22	.0064	39.4
NOx	HDGV	3.1	5.15	.036	7.0
NOx	HDDV	6.2	13.58	.12	2.1

[1] gm/mile change in the composite emission factor per 1% increase in this vehicle type.

Notes: Difference in emissions due to vehicle type are greatest for hot (95°F) weather, which are the conditions shown in this table. Vehicle types are as follows:

ALL = all vehicle composition
LDGV = light-duty gasoline vehicles (passenger cars)
LDGT2 = gasoline trucks 6000-8500 lbs.
HDGV = gasoline trucks >8500 lbs. gross wt.
HDDV = heavy-duty diesel trucks (18 wheelers)

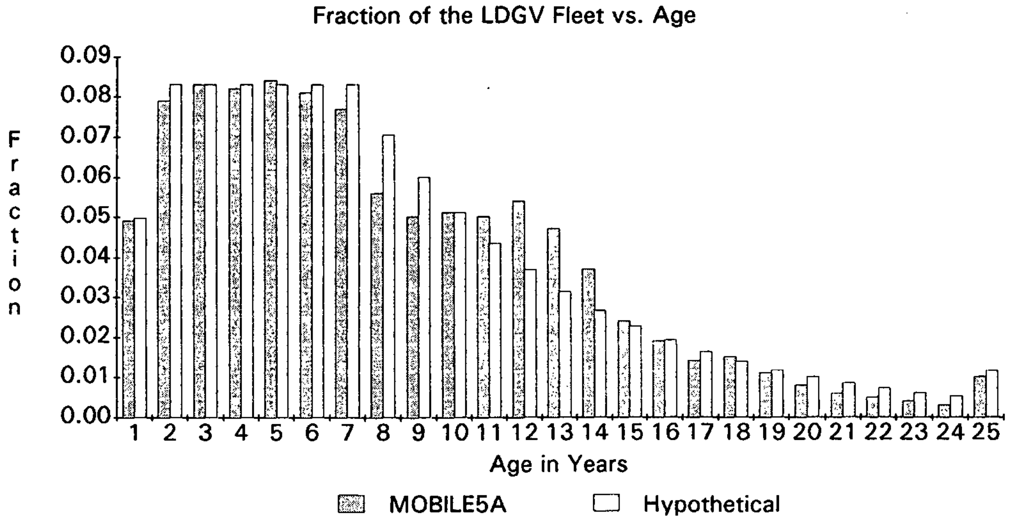


Figure 4-13. Vehicle age distribution.

actual age mix of a local area, measured by the median vehicle age, could easily be off 1 year or more from the default 6.5-year value used in the MOBILE5a model. Even when local vehicle registration data are used instead of the default age mix in the MOBILE5a model, the age of vehicles traveling through the area from out of state will not be addressed.

The CAAA requires that 1994 model and later cars meet prescribed emission limits throughout the first 100,000 miles of operation. If new vehicles can meet these requirements, the effects of increased emissions because of deterioration will be greatly reduced.

VEHICLE-MILES TRAVELED

Mobile source emissions are estimated by multiplying emissions factors in grams per mile by the VMT, which the EPA usually refers to as an "activity factor." In detailed emission inventories, VMT is estimated link by link for the transportation system for the day of interest and summed to give daily emissions for the area. Emission estimates are directly related to VMT, so that a 10 percent error in VMT creates a 10 percent error in the emission estimate. VMT for emission estimates can be determined by direct measurement (vehicle counting), by extrapolation from short-count data, or from computerized travel estimation models. Daily VMT on a highway link is equal to the ADT for the highway link multiplied by the link length (in miles).

Errors in VMT depend on the estimation method employed. Link lengths can be determined with minimal error, so most error in VMT comes from errors in vehicle counts or traffic volume estimates. The most accurate vehicle counts come from continuously monitored sections of roadway using induction loops embedded in the pavement to sense vehicles as they pass. All vehicles do not create the same signal, so there is some error even in continuous counting stations. Short-term counts (i.e., a few days or weeks) are often taken with rubber

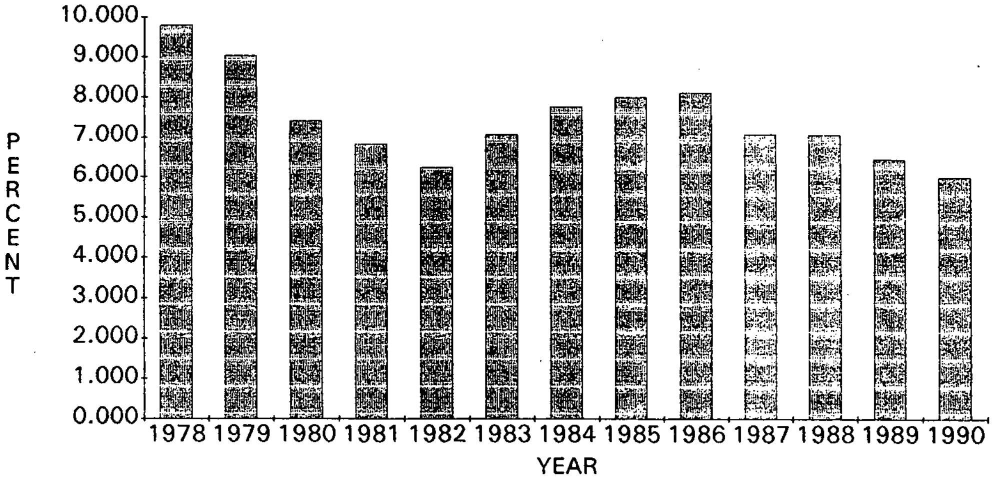


Figure 4-14. U.S. car sales as a percentage of the existing fleet.

TABLE 4-5 Default vehicle age distribution used in the MOBILE5a model and hypothetical age distribution for newer and older fleets

			Hypothetical Age Distributions			
Vehicle Age	Default Fractions of Fleet (percent)	Default Cumulative (percent)	More New Cars Cumulative (percent)	More Old Cars Cumulative (percent)	More New Cars Fractions of Fleet (percent)	More Old Cars Fractions of Fleet (percent)
1	0.049	0.049	0.1	0.025	0.1	0.05
2	0.079	0.128	0.25	0.067	0.15	0.042
3	0.083	0.211	0.4	0.12	0.15	0.053
4	0.082	0.293	0.56	0.175	0.16	0.055
5	0.084	0.377	0.67	0.24	0.11	0.065
6	0.081	0.438	0.74	0.3	0.07	0.06
7	0.077	0.535	0.79	0.36	0.05	0.06
8	0.056	0.591	0.83	0.42	0.04	0.06
9	0.05	0.641	0.86	0.48	0.03	0.06
10	0.051	0.692	0.9	0.54	0.04	0.06
11	0.05	0.742	0.91	0.59	0.01	0.05
12	0.054	0.736	0.92	0.65	0.01	0.05
13	0.047	0.843	0.93	0.7	0.01	0.05
14	0.037	0.88	0.94	0.74	0.01	0.04
15	0.024	0.904	0.95	0.79	0.01	0.04
16	0.019	0.923	0.955	0.83	0.005	0.04
17	0.014	0.937	0.96	0.85	0.005	0.02
18	0.015	0.952	0.965	0.9	0.005	0.02
19	0.011	0.963	0.97	0.92	0.004	0.02
20	0.008	0.971	0.976	0.94	0.005	0.02
21	0.006	0.977	0.98	0.95	0.005	0.01
22	0.005	0.982	0.985	0.96	0.005	0.01
23	0.004	0.986	0.99	0.97	0.005	0.01
24	0.003	0.989	0.995	0.98	0.005	0.01
25	0.001	0.999	0.999	0.999	0.004	0.019
	Median Age 4.5 Years				Median Age 3.5 Years	Median Age 9.5 Years

TABLE 4-6 Sensitivity of MOBILE5a emission factors to changes in the median age of the vehicle fleet

		Emission factors				
Pollutant	Vehicle Type	Median Age 3.5 Years	Median Age 6.5 Years	Median Age 9.5 Years	Slope (%/Yr.) for 1 Year Newer	Slope (%/Yr.) for 1 Year Older
CO	LDGV	12.54	20.42	27.61	-12.9	+11.7
CO	LDGT2	17.59	32.99	37.12	-15.6	+4.2
CO	ALL	13.78	23.51	28.8	-13.8	+7.5
VOC	LDGV	1.47	2.22	2.98	-11.3	+11.4
VOC	LDGT2	1.97	3.71	4.16	-15.6	+4.0
VOC	ALL	1.66	2.59	3.2	-12	+7.8
NOx	LDGV	1.08	1.6	2.02	-10.8	+8.8
NOx	LDGT2	1.52	2.32	2.54	-11.5	+3.2
NOx	ALL	1.88	2.56	3.03	-8.8	+6.1
Replacement Rate		15%/Yr.	8%/Yr.	5%/Yr.		

Notes: Slopes equal the percent change in emissions rates per 1-yr change in the median vehicle age. Vehicle types are as follows:

ALL = all vehicle composition
LDGV = light-duty gasoline vehicles (passenger cars)
LDGT2 = gasoline trucks 6000-8500 lbs.

pneumatic tube and sensors which count axles. Large trucks have five axles, while passenger cars have two. This introduces count errors related to the number of trucks on the roadway.

All states report annually to the FHWA the results of statewide vehicle counting programs as part of the national HPMS. These results, reported as average annual daily traffic (AADT), reflect a combination of continuous monitoring station counts on relatively few links and periodic counts usually lasting 1 to 2 days at hundreds of locations across a state. The periodic counts are adjusted to AADTs on the basis of historical adjustment factors (from continuous monitoring sites) that account for monthly and day-of-week variations in daily traffic. Under HPMS, VMT is estimated by expanding, or factoring up, the VMT on sample road segments to the universe. (More detailed discussion on this procedure is provided in Chapter 2.)

Other procedures of estimating VMT, such as stepwise travel demand models, also are prone to errors from various sources. Many travel models do not consider the VMT on local streets (or even minor collectors). The EPA (1989) provides national average estimates of VMT on local streets equal to 13.9 percent of total travel. Fleet and DeCorla-Souza (1991) of FHWA have reported an expected precision for AADTs on the basis of short counts at ±10 percent for arterials and, for statewide systems with 2,000 samples, at ±5 percent. Walker and Peng (1995) investigated modeled traffic volumes compared with measurements at screenlines and found an average error of 5.4 percent. VMT errors are likely to be larger than errors in traffic volume estimates because of the additional errors in estimating trip lengths. Given the potential sources of error in traffic counts and other VMT estimation procedures, estimates of VMT probably contain errors of at least 5 to 10 percent and perhaps considerably higher depending on the extensiveness of the traffic counting and/or travel modeling system used and the care taken in maintaining and handling data.

COMBINED EFFECT OF ERRORS IN INPUT PARAMETERS

The previous sections included discussion and analysis of errors in transportation-related input parameters of MOBILE5a and showed how the value of an emission factor would be affected by estimation errors associated with individual input parameters. The slopes given in Tables 4-1 through 4-4 and Table 4-6 can be used to estimate the magnitude of the error in emission rates caused by the misspecification of parameters of speed, cold- and hot-start fractions, vehicle type, and median age of a vehicle fleet respectively. In actuality, estimation errors probably would occur with several of these input parameters simultaneously; therefore, planners need to consider what will be the combined effect of these multiple errors on emission rates. To gain insight into this issue, three hypothetical cases were developed and analyzed with the MOBILE5a model. On the basis of the speed values used, these cases will be called freeway, arterial, and collector cases respectively.

Case 1: Freeway

For this case, three sources of error were introduced—speed, HDDV fraction, and median vehicle age. It was assumed that the correct/true values for these three parameters were 65 mph, 10.6 percent, and 7.5 years, respectively, whereas the estimated values for these were 60 mph, 6.2 percent, and 6.5 years. (Each value for HDDV fraction and median vehicle age was associated with a vehicle/VMT mix and vehicle age distribution, respectively.) Two separate MOBILE5a runs were made with these two sets of input values, keeping the values of other input parameters the same for the two runs. The results, presented in Table 4-7, show how the error in each input parameter affects emission rates individually and also what the combined effect of three sources of error is. Each percentage value presented represents the difference of the true/actual value of an emission rate with respect to the estimated emission rate expressed as a percent of the estimated rate. For example, the combined effect of the three sources of error in the case of CO is +46 percent, meaning that the true/actual value is 46 percent higher than the estimated value. The combined effect for CO in this case is fairly large, and the major source of this effect is the speed estimate.

Case 2: Arterial

In this case, four input parameters were analyzed—speed, VMT mix, vehicle age, and operating mode. Two sets of values were developed for these parameters, keeping the other input parameters at the same levels, and MOBILE5a was run for the two different sets. The results, shown in Table 4-7, indicate the effect of error in individual parameters and the combined effect of all four sources of error.

Case 3: Collector

This case deals with three input parameters—speed, cold starts, and vehicle age. It is assumed that the speed is overestimated, cold-start fraction is underestimated, and vehicle age is estimated to be lower (i.e., newer) than the true age. As for the other two cases, two sets of runs were made with MOBILE5a, and the results were compared and analyzed to identify the effect of each source of error individually and in combination. The results, presented in Table 4-7, indicate how, on occasion, the difference between the true value and estimated value can become magnified with errors from different sources acting simultaneously. In particular, the combined effect for NO_x is greater than the sum of the individual effects.

Pattern of Combined Error and Effect

The direction of the effects of different sources of error was expected to play a role in the determination of the com-

TABLE 4-7 Individual and combined effects of input errors

Case	Input Parameter	True Value vs. Estimated Value	Percentage Difference in Emission Rates[1] CO	VOC	NOx
Freeway	Speed	65 vs. 60 mph	+42%	+13%	+16%
	HDDV Mix	10.6 vs. 6.2%	-1%	-1%	+18%
	Median Age of Vehicles	7.5 vs. 6.5 yrs	+7%	+8%	+6%
	All Three Combined (Compounded Effect)		+46%	+19%	+44%
Arterial	Speed	45 vs. 40 mph	-8%	-7%	+3%
	HDGV Mix	1.0 vs. 3.1%	-8%	-4%	-3%
	Median Age of Vehicles	5.5 vs. 6.5 yrs	-14%	-12%	-9%
	Cold Start Fraction	10.6 vs. 20.6%	-15%	-23%	-2%
	All Four Combined (Compounded Effect)		-38%	-28%	-15%
Collector	Speed	20 vs. 25 mph	+22%	+17%	+0.4%
	Median Age of Vehicles	7.5 vs. 6.5 yrs	+7%	+8%	+6%
	Cold Start Fraction	30.6 vs. 20.6%	+15%	+23%	+2%
	All Three Combined (Compounded Effect)		+38%	+32%	+9%

[1] These percentages were calculated as [(True Value - Estimated Value) ÷ Estimated Value].

bined effect. It was anticipated that the combined effect would exceed the sum of the individual effects when all signs were in the same direction and that mixed signs would dampen the combined effect. No such clear pattern exists in the data. This can be seen in Table 4-8.

The only pattern observed is that the combined effect for NO_x is always higher than its component parts and the combined effect for CO and VOCs is always smaller than the sum of their components. Not enough conditions were observed to know whether this pattern holds over a broad range of parameter values.

CONCLUSIONS

On the basis of the results of a sensitivity analysis of the MOBILE5a emissions model, it was found that the emission factors calculated by the model vary substantially when the travel-related inputs to the model are varied within the usual ranges of accuracy and precision expected with the current state of the practice in transportation planning. An error of 5 mph in the estimated value of speed for a freeway can cause a 42 percent difference in CO emission factor. A 4.4 difference in percent in HDDV mix can cause an 18 percent difference in NO_x emission factor. A 10.0 difference in percent of cold-start fraction can cause a 23 percent difference in VOC emission factor. The combined effect of the individual errors can create a difference in certain emission factors of nearly 50 percent. These errors in input factors are within reasonable and realistic limits and are not exaggerated—the effect of these errors on emission factors should be of serious concern.

TABLE 4-8 Pattern of combined error[1]

Case	Direction of Individual Errors: All Same Sign	Mixed Signs
Freeway	NOx higher	CO lower VOC lower
Arterial	CO lower VOC lower	NOx higher
Collector	CO lower VOC lower NOx higher	

[1] The table shows how the combined error compared with the algebraic sum of individual errors.

With regard to the combined effect of different sources of error, the directions of errors in individual input parameters are unpredictable. It would be unwise to expect and rely on the compensatory effect of individual errors; rather, it would be prudent to recognize the likelihood of cases where the individual errors may be compounded to high levels. The three cases presented above represent realistic scenarios; the results point to the possibility of large errors in emission rates caused by errors in travel-related inputs to MOBILE5a.

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CHAPTER 5

ERROR ANALYSIS FOR SPEED AND VMT MIX

INTRODUCTION

State and local transportation practitioners routinely are asked to provide transportation-related data for the air quality planning process. Sufficient data and field experience exist for a detailed examination of the variability of two key transportation inputs: vehicle speeds and vehicle type mix; these are the focus of this chapter. Because the methods and data in use vary, the approach taken, wherever choices of methods or data exist, is to assume the "best practice available." These decisions reflect the research team's experience with the methods available to state and local planners in the field.

Risk-Based Sensitivity Analysis

The methodology selected to study the implications of the errors associated with MOBILE5a input estimation is risk-based sensitivity analysis. This form of sensitivity analysis is far more involved than traditional sensitivity analysis and requires great detail in the inputs as well as multiple runs of MOBILE5a for a particular set of input conditions. In risk-based sensitivity analysis, probability distribution functions (PDFs) are established for each of the factors (i.e., MOBILE5a inputs) to be studied. These distributions are based either on empirical evidence or expert judgment and are converted to cumulative probability distributions. The factor levels for a particular run of the model are then set by using Monte Carlo simulation; this is done by generating a random number and sampling from the distributions. In this way, the errors associated with estimating the inputs can be traced through to their effect on the outputs. The final output from this procedure is a PDF for the process under study, in this case, PDFs for each emission factor. As a consequence, risk-based sensitivity analysis provides not only an estimate of the range of possible outcomes but the relative likelihood of occurrence for the possible outcomes. Therefore, risk-based sensitivity analysis provides a quantitative assessment of the errors associated with MOBILE5a outputs. The method of risk-based sensitivity analysis is simple—the crucial step is determining the PDFs of the factors under study. Considerable effort went into quantifying the errors inherent in estimating speeds and vehicle mix.

Precision Versus Accuracy

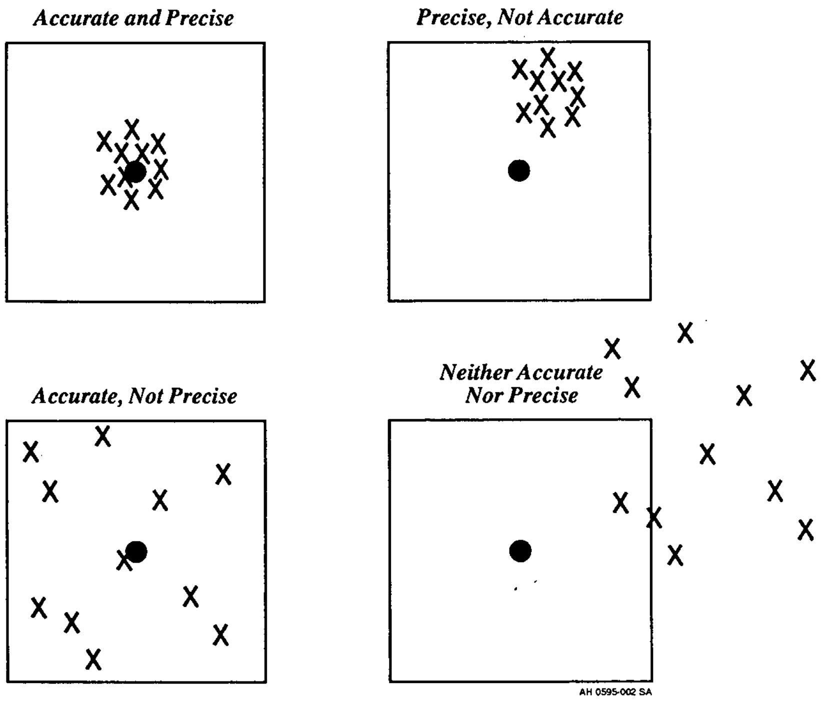
Although the distinction between precision and accuracy may seem artificial, this distinction is extremely important for understanding the errors associated with transportation data. Precision is the "degree of repeatability" of estimates; accuracy is the "closeness" of estimates to a "true" value (Figure 5-1). In statistical terms, precision relates to the variance of the estimates while accuracy relates to the mean of the estimates. Ideally, estimates should be both accurate and precise; in practice, knowledge of the "true" value of a phenomenon often is unobtainable. Risk-based sensitivity analysis is a good tool for estimating precision, but it does not address accuracy. Therefore, additional discussions on the accuracy of transportation inputs wherever data allow such an analysis have been included.

PRECISION OF SPEED ESTIMATES FOR MOBILE5A

Background

Vehicle speeds are a crucial input to MOBILE5a and have been shown to influence the resulting emission factors significantly. As defined in MOBILE5a, the speed input variable is the average speed of all vehicles in the time frame and geographic location under study. To be perfectly compatible with the MOBILE5a definition, speeds should be the *average route speed* of vehicles as they travel on a network instead of spot speeds at particular locations.

The most common method for estimating speeds for air quality planning involves the use of stepwise travel forecasting models (sometimes called "network models"). The models are used to estimate demands on the highway and transit systems by forecasting volumes on a network that represents the transportation system. The procedure is typically accomplished in three or four sequential steps. Traffic assignment procedures (the final step) provide two major outputs for each link in the highway network—predicted traffic volume and speed. Traditionally, the major purpose of the assignment process for transportation planners has been to obtain traffic volume for each highway facility; the corresponding speeds tend to be treated only as intermediate variables required to obtain realistic volumes. Recently, the influence of forecast congestion has been recognized as a determinant



Accuracy – on target, on the average (adherence to a predetermined standard)
Precision – scatter (how tight are confidence bounds)

Figure 5-1. Statistical accuracy and precision.

of travel patterns. That is, as congestion on a link increases, travelers will respond by altering their travel behavior. The behavior shift in the short term is to find an alternate route for the trip—this feature is embedded in current travel forecasting models, however, persistent congestion may cause travelers to alter their trip-making more significantly by switching their destinations or time of travel. (For example, if the closest grocery store to a person's home is on a heavily congested route, the individual might choose to shop at a more distant store on an uncongested route.) Finally, chronic long-term congestion will cause changes in the land development patterns in an area. To address these occurrences, planners have started to use travel forecasting models iteratively. In this approach, the speeds from one pass through the models are "fed back" into early stages to incorporate the influence of congestion on travel behavior. However, the speeds that result from the traffic assignment process are a by-product of that process and are felt to be too crude for use in anything other than the achievement of realistic traffic flows. Therefore, planners have begun to modify the speed estimation process in the following ways:

- Improve the link speed prediction process incorporated in the traffic assignment procedure by including better estimates of capacities, free-flow speeds, and speed-volume functions or
- Accept the traffic volume generated by the current highway assignment process, supplemented by a post-processing capability that provides improved link speed estimates.

Even when these improvements are instituted, the results are an abstraction of reality. The modified process, which is adequate for estimating total network flows, still has shortcomings for detailed speed estimation. The main problem is the influence of congestion over time, namely, that the effect of standing queues created in the peak hour are not considered. Also, any of the "improved" speed functions remain simplifications and do not fully consider the effect of intersection delays and other determinants of speeds, such as signal density, grades, curves, or parking. (Cambridge Systematics, 1994).

Planners and researchers have devised several alternative speed-volume functions to the standard BPR function (Table 5-1). Planners occasionally "tinker" with the exponents of these functions to achieve improved traffic assignments. In all cases, the variant functions degrade speed more sharply as the V/C ratio increases. These functions can be used either directly in the traffic assignment process or as post-processors. In addition to these functions, other post-processor methodologies also have been developed, the most common of which are based on the *Highway Capacity Manual*.

TABLE 5-1 Speeds predicted by BPR function and its variants

V/C	BPR	Ruiter (S_c = 25 mph)	Ruiter (S_c = 50 mph)	CSI/JHK	Mod BPR4	Mod BPR10	Davidson (J = 0.04)
0.10	60.00			60.00	59.99	60.00	59.73
0.50	59.44			59.97	56.47	59.94	57.69
0.75	57.28			59.27	45.58	56.80	53.57
0.90	54.62			56.99	36.23	44.49	44.12
0.95	53.47			55.49	33.07	37.53	34.09
1.00	52.17	24.98	49.70	53.45	30.00	30.00	N/A
1.05	50.75	23.46	46.68	50.80	27.08	22.82	
1.10	49.20	22.21	44.18	47.52	24.35	16.70	
1.15	47.53	21.17	42.10	43.64	21.83	11.89	
1.20	45.77	20.30	40.35	39.30	19.52	8.34	
1.30	42.00	18.93	37.60	30.01	15.56	4.06	
1.40	38.07	17.92	35.59	21.37	12.39	2.00	
1.50	34.10	17.16	34.08	14.49	9.90	1.02	
1.60	30.26	16.58	32.92	9.58	7.94	0.54	
1.70	26.63	16.13	32.02	6.29	6.42	0.30	
1.80	23.30	15.78	31.31	4.14	5.22	0.17	

Notes:

FFS = free-flow speed.

S_c = speed at capacity.

Functions: BPR = FFS/(1 + (0.15 • $(V/C)^4$)); Ruiter = S_c • (0.555 + (0.444$(V/C)^3$)); CSI/JHK = FFS/(1 + (0.1225 • $(V/C)^8$)); Mod BPR4 = FFS/(1 + $(V/C)^4$); MOD BPR10 = FFS/(1 + $(V/C)^{10}$); Davidson = FFS/(1 + (0.04 • (V/(V))).

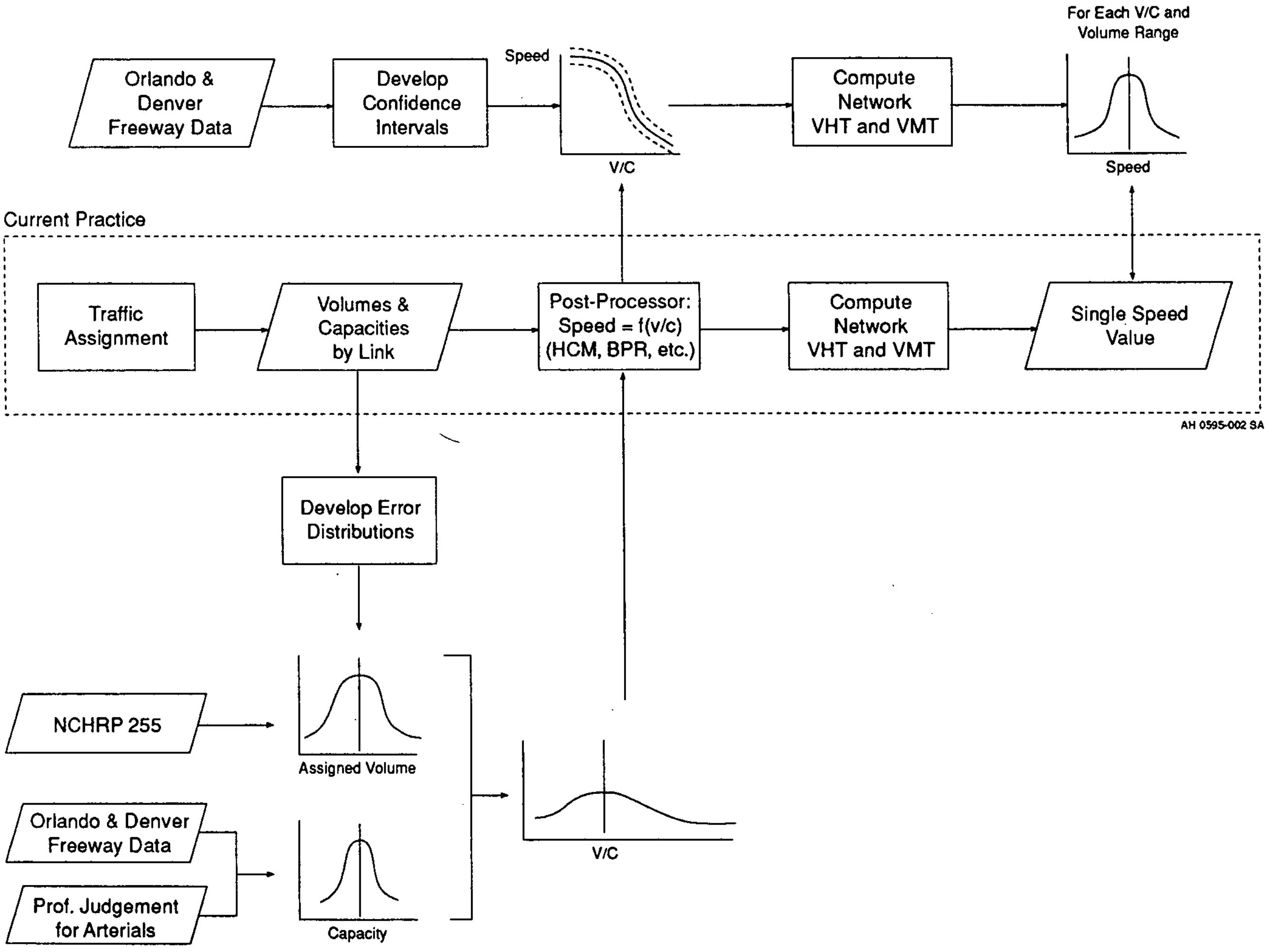
Methodology

The methodology for studying the precision of speed estimates is based on the post-processor approach (Figure 5-2). The current practice for post-processing speeds is shown in the long dashed box. Volumes and capacities for each link in the network are used as input to the post-processor methodology, which produces estimates of link speed. VHT and VMT are computed for each link and summed over the entire network. Overall average network speed is computed as VMT divided by VHT. The average speed of roadways of each functional class can be estimated in a similar manner.

Errors can influence this sequence of events at several points. The assigned link volumes and the estimated link capacities can be in error. Also, the post-processor methodology will be subject to some error. Estimation of these errors is based on past research, analysis of freeway speed data, and professional judgment as detailed below. Risk-based sensitivity analysis is used to develop error distributions for each step in the process. Because substantial operating differences exist between interrupted flow (arterial) and uninterrupted flow (freeway) facilities and between free-flow versus forced-flow (congested) conditions, the error estimation is broken into these four categories. The "best practice" post-processor methodologies were then selected for each of the four categories.

Precision of Assigned Volumes

Travel forecasting models typically are calibrated to existing conditions by comparing assigned volumes for a recent year to actual volumes for links where traffic counts exist. It is common for assigned volumes to deviate from actual volumes; therefore, calibration is continued until a reasonable match is obtained. *NCHRP Report 255* (TRB, 1982) provides guidance to practitioners as to what is considered to be "reasonable" (Figure 5-3). The guidance is designed to allow for greater deviation for low-volume roads and less deviation for high-volume roads, because high-volume roads are of greater interest from both future investment and congestion perspectives. (If operating conditions on low- and high-volume facilities are the same—as measured by the V/C ratio—more vehicles are exposed to delay on the high-volume facility.) The measure used in Figure 5-3 to gauge differences in assigned and counted traffic volumes is "maximum desirable deviation." This is not a strict statistical term but is used as a practical guideline for practitioners; however, this term must be converted to correspond with statistical theory because the analysis technique used here reflects the measures of variability used in statistics, that is, means and standard deviations. In this case, the mean becomes the volume count and the standard deviation measures the variability in estimating that mean value. Given that *NCHRP Report 255* defines the deviation as the *maximum* desirable, the variability allowed around the volume (i.e., the mean) should be large. Therefore, one assumes that the spread of error around the volume as defined in Figure 5-3 should correspond to the 99 percent confidence interval around that volume. For example, consider a base-year traffic count of 50,000 vehicles per day. Figure 5-3 indicates that the maximum desirable deviation of a model-produced ("assigned") estimate is approximately 21 percent. In other words, ide-



Note: The standard normal distribution is assumed.

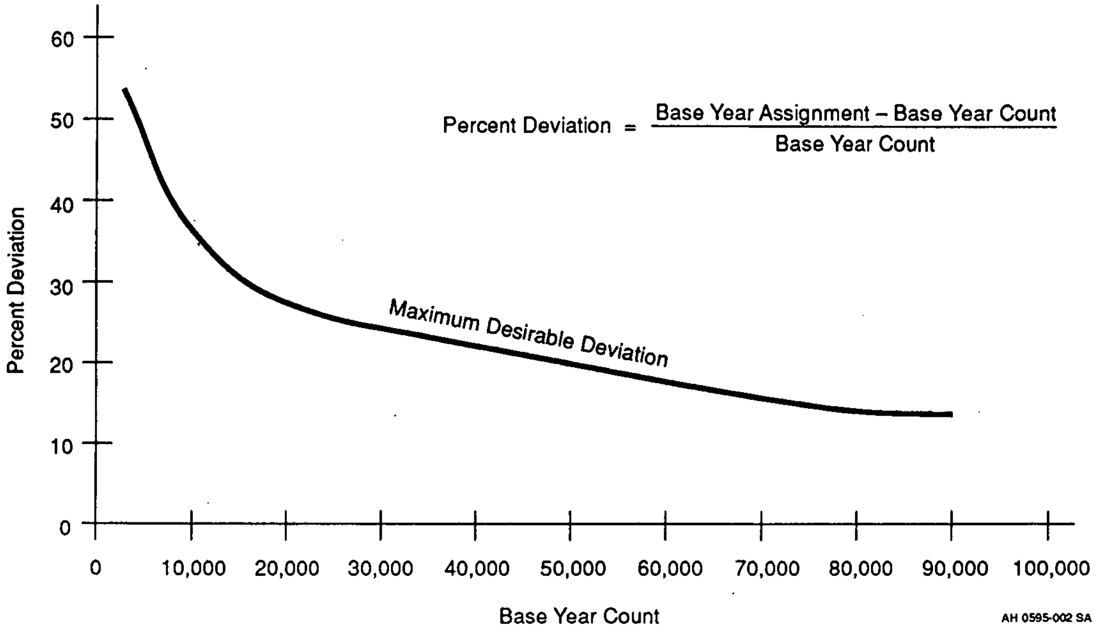
Figure 5-2. Risk-based sensitivity analysis for speed.

ally, the assigned volume should be within the range of 39,500 and 60,500 vehicles per day. This range of values is then assumed to represent the 99 percent confidence interval.

Assuming that *NCHRP Report 255* is widely used as guidance and that the maximum desired deviation in Figure 5-3 corresponds to the 99 percent confidence interval for assigned volumes, distributions can be developed with the knowledge that, in a normal distribution, 99 percent of the observations fall within 2.58 times the standard deviation of the mean. Because the results vary with volume (as shown in Figure 5-3), different distributions must be developed for different volumes. Also, the 24-hour, two-way volumes in Figure 5-3 must be converted to hourly volumes in one direction to be compatible with the hour-based post-processors. (Post-processors use the V/C ratio as the independent variable where V is the hourly volume and C is the hourly capacity.) The results are shown in Table 5-2.

Precision of Capacity Estimates

The *Highway Capacity Manual* provides procedures for estimating the capacity of highway facilities with different operating characteristics, where capacity is defined as the maximum number of vehicles that can be accommodated in one lane for a 1-hr period (vehicles per hour per lane or vphpl). When volume exceeds capacity, forced flow ("stop-and-go") occurs. The factors that determine capacity include the geometric design of the facility (e.g., lane width), traffic control device characteristics (e.g., signals), and the percent of trucks. To evaluate potential variability in capacity estimates, the research team obtained freeway data from the Orlando, FL, and Denver, CO, freeway surveillance systems. These data represent field measurements of speeds, volumes, and densities taken every 5 min at closely spaced (about $^1/_2$ mi) intervals along the freeways. (Orlando's system covers 12 mi and includes 25 measurement locations while Denver's covers 9 mi and includes 12 locations.) Speed-volume



Source: NCHRP 255

Figure 5-3. Desired assigned volume errors from travel forecasting models.

curves closely resembling those in the *Highway Capacity Manual* can be generated from these data (Figures 5-4 and 5-5). The curves show the two operating regimes—high speeds and low volumes indicate free-flow conditions while low speeds indicate forced-flow conditions. The curves double back on themselves after reaching a maximum flow rate (i.e., capacity). This feature suggests that after forced flow has begun, capacity actually drops to a value less than the original value; in stop-and-go traffic, it is no longer possible to obtain the theoretical capacity flow rate. Thus, a volume of 1,500 vphpl can exist in both regimes: under free-flow conditions, its corresponding speed might be 55 mph; under forced flow, it might be around 20 mph. Another interesting feature of these curves is the difference in the free-flow speeds, defined as the speed under very low volumes. Examination of the data shows the average free-flow speed for Orlando to be around 57 mph while for Denver it is approximately 62 mph. The two freeway sections have nearly the same geometrics (i.e., similar lane width, lateral clearance, curves, and grades) and average percent trucks (around 7 percent) The Orlando section has a higher interchange density—this is probably what produces the lower speeds. However, in both cases, the free-flow speed is higher than the 55 mph speed limit in effect in both places.

These data can be used to examine the variability in capacity as measured by the field data. In theory, the capacity of a section should be constant; however, the *Highway Capacity Manual* does not consider such factors as weather, pavement condition, and lighting. Also, the percent of trucks on a section will vary from hour to hour causing

TABLE 5-2 Precision of volumes from traffic assignment

Facility Type	V/C	AADT	Hourly Volume[1]	Max. Desired Deviation[2]	Standard Deviation[3]	Coefficient of Variation[4]
4-Lane Freeway	0.70	48,800	2,930	21%	238	8.1%
	1.15	80,000	4,814	15%	280	5.8%
4-Lane Arterial	0.70	21,000	1,260	28%	137	10.9%
	1.15	34,500	2,070	24%	193	9.3%

[1] Assuming that 10% of daily traffic occurs in the peak hour and 60% of peak hour traffic occurs in the peak direction.
[2] From Figure 5-3. This corresponds to the 99% confidence interval.
[3] Equals (hourly volume • max desired deviation) divided by 2.58.
[4] Equals the standard deviation divided by hourly volume.

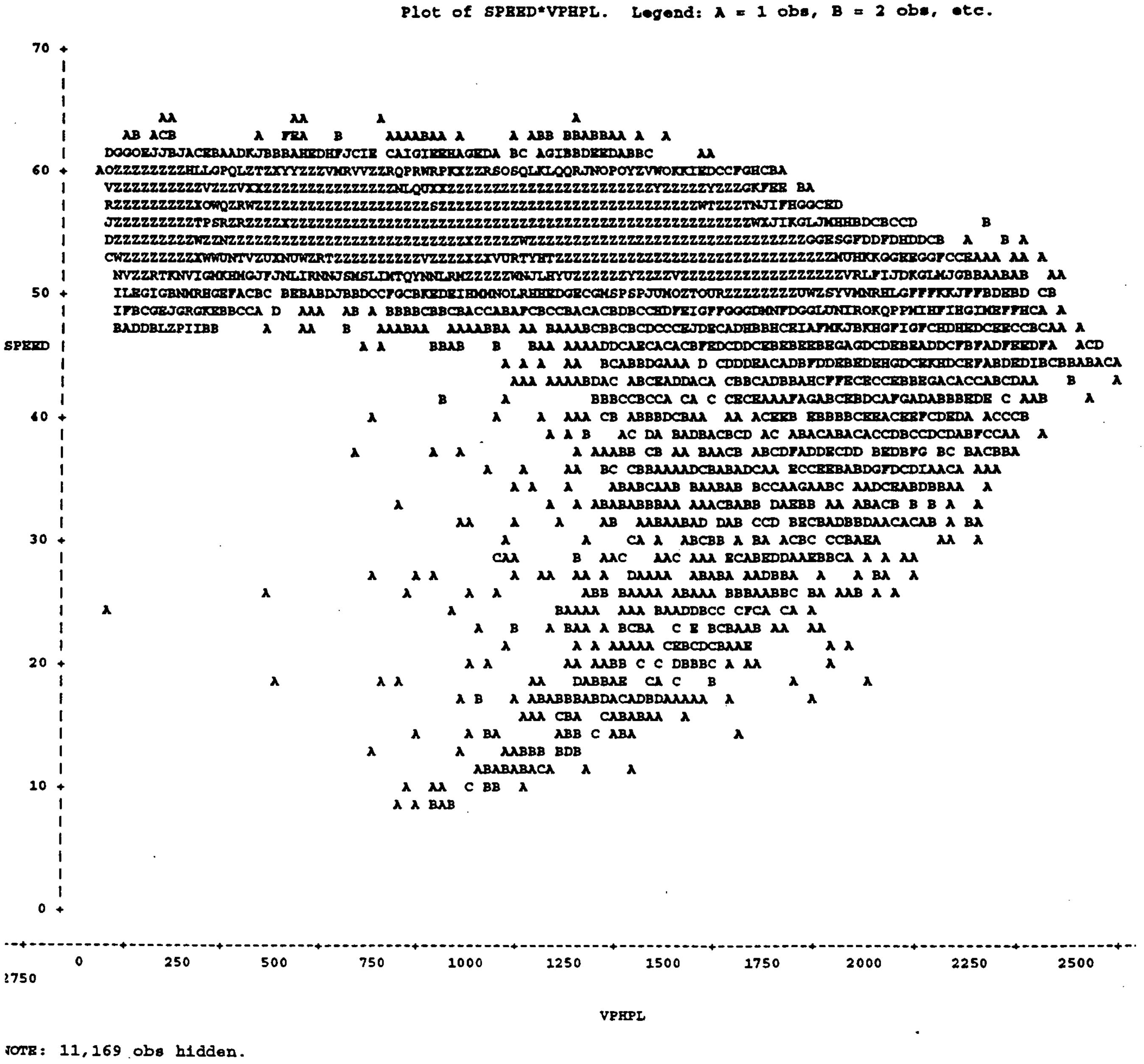
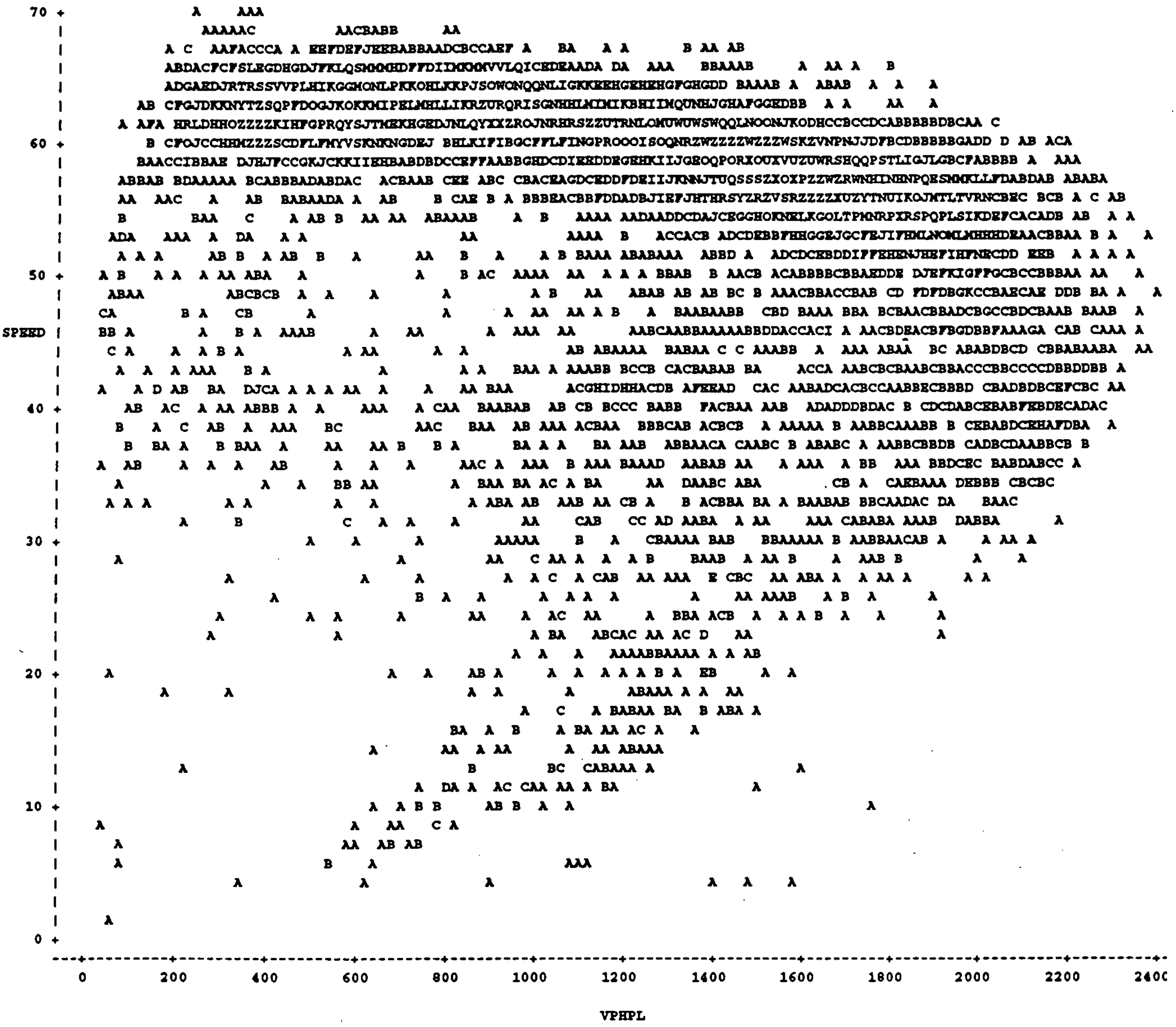


Figure 5-4. Speed-volume data for I-4 in Orlando.

capacity to fluctuate. Finally, as traffic approaches the capacity of a section, the effect of minor disruptions in the traffic stream becomes more pronounced. For example, in tightly spaced traffic, actions by even one driver can cause the onset of forced flow. Therefore, the sequence of driver and vehicle types in the traffic stream is important but impossible to measure. From a planning perspective, capacity must be viewed as an average value rather than an absolute value. The concept of an average value implies that a distribution of values also exists, and the freeway data were used to estimate this distribution in the following way. Using the *Highway Capacity Manual* and data provided by field personnel, the capacity at each measurement location was calculated. Most locations in each city had the same capacity; those that did not were excluded. The distribution was assumed to include values above and below the theoretical capacity. To capture those cases higher than the theoretical capacity, any hours where volume was greater than or equal to capacity were identified. For those below capacity, the V/C ratio had to be between 0.9 and 1.0, and the density of vehicles had to be between 40 and 42 vehicles per lane-mile. (This is the density at capacity suggested by



NOTE: 178 obs hidden.

Figure 5-5. Speed-volume data from I-25 in Denver.

the *Highway Capacity Manual.*) Using this information, the average capacity for Orlando sites was 2,283 vphpl with a coefficient of variation of 5.1 percent. For Denver sites, the average capacity was 2,179 vphpl with a coefficient of variation of 3.9 percent. The theoretical capacities were 2,193 vphpl for Orlando, FL, and 2,126 for Denver, CO, on the basis of the 1994 edition of the *Highway Capacity Manual.*

Precision of V/C Estimates

The precision of V/C estimates, the key input to speed post-processors (sometimes the only input), is found by combining the distributions for assigned volumes and capacities determined above using risk-based sensitivity analysis. Because the percentiles of the volume distributions vary, several volume levels were assessed; the results appear in Table 5-3.

Free-Flow Freeways

The speed-volume plots shown in Figures 5-4 and 5-5 can be modified to exclude any measurements taken under forced-flow conditions by establishing density cutoff points as specified in the *Highway Capacity Manual* (42 vehicles per lane-mile, as previously stated). Also, the ordinate can be easily changed to V/C rather than volume. The resulting plots are shown in Figures 5-6 and 5-7. A check against the speed

TABLE 5-3 Precision of V/C estimates

V/C Ratio	Volume	Coefficient of Variation
0.70	High	6.9%
	Low	9.3%
	Combined	8.2%
1.15	High	5.8%
	Low	7.3%
	Combined	6.6%

functions in Table 5-1 revealed that the original BPR function provides the proper equation form for estimating speeds on free-flow freeways. However, the original data with which the BPR curve was developed could not be located; these data are necessary to determine the goodness-of-fit of the equation. Therefore, the data in Figures 5-6 and 5-7 were used to fit regression equations assuming the BPR form; this involves estimating the coefficient of the V/C term (0.15 in the original equation). The results appear in Table 5-4.

The Denver data show a better fit to the equation form (higher R^2 value) but the V/C coefficient is somewhat different than the original. The Orlando data replicate the V/C coefficient almost exactly but the fit is not as good as the Denver data. Confidence intervals also can be placed around the predictive equations, as shown in Table 5-4. These can be used to estimate the range of variability in obtaining speed estimates with the equations. As shown, the width of the 95 percent confidence interval is approximately ±5 mph.

The information on the goodness-of-fit of the BPR curve can be combined with the error distribution for V/C estimation by again applying risk-based sensitivity analysis. This involves the following steps:

1. Select a V/C ratio below 1.0 to be studied. Example: select 0.5 as the mean value.
2. Randomly sample from the V/C error distribution to select a V/C value around the previously selected mean value. This step is done because an estimate of V/C is

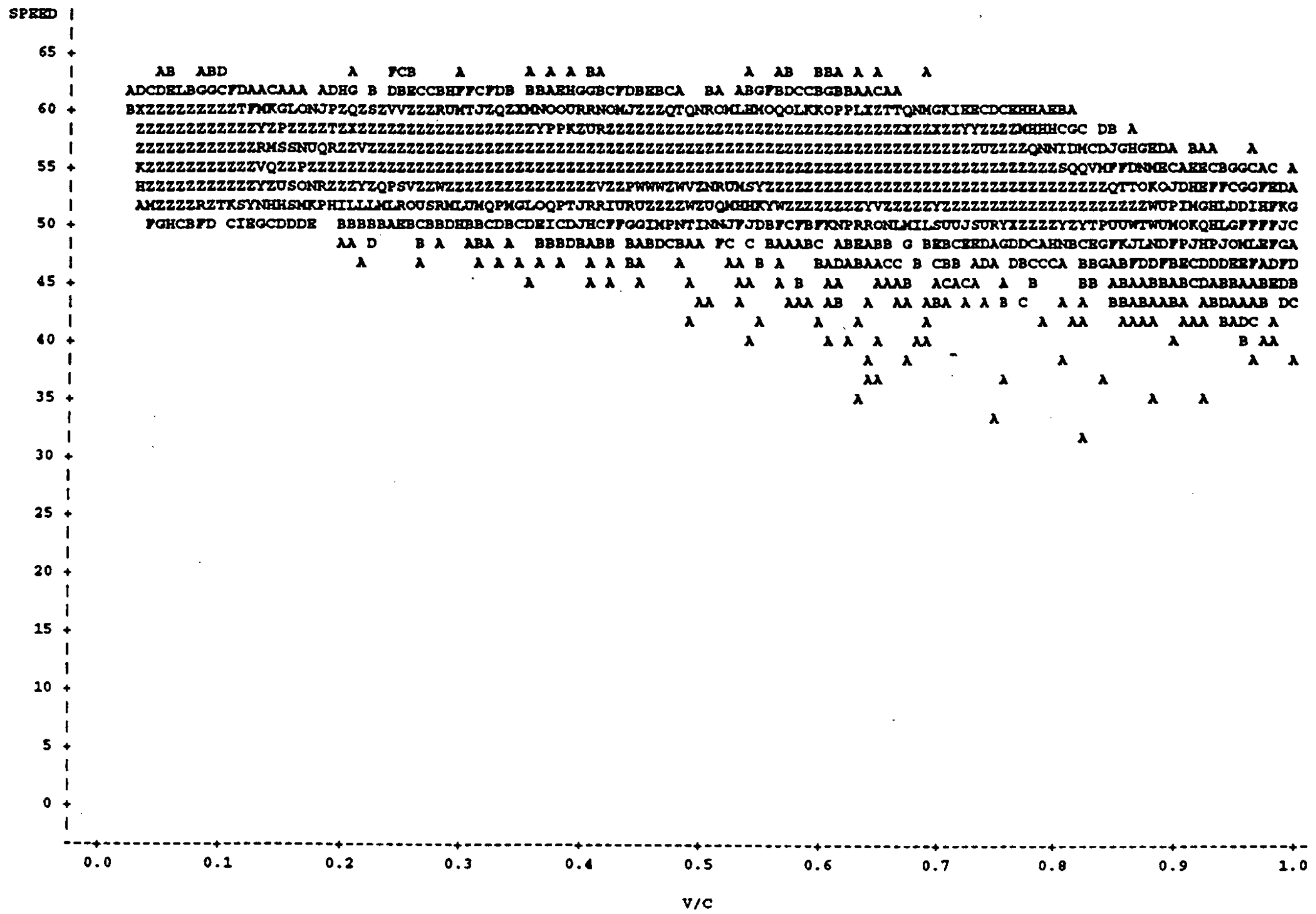


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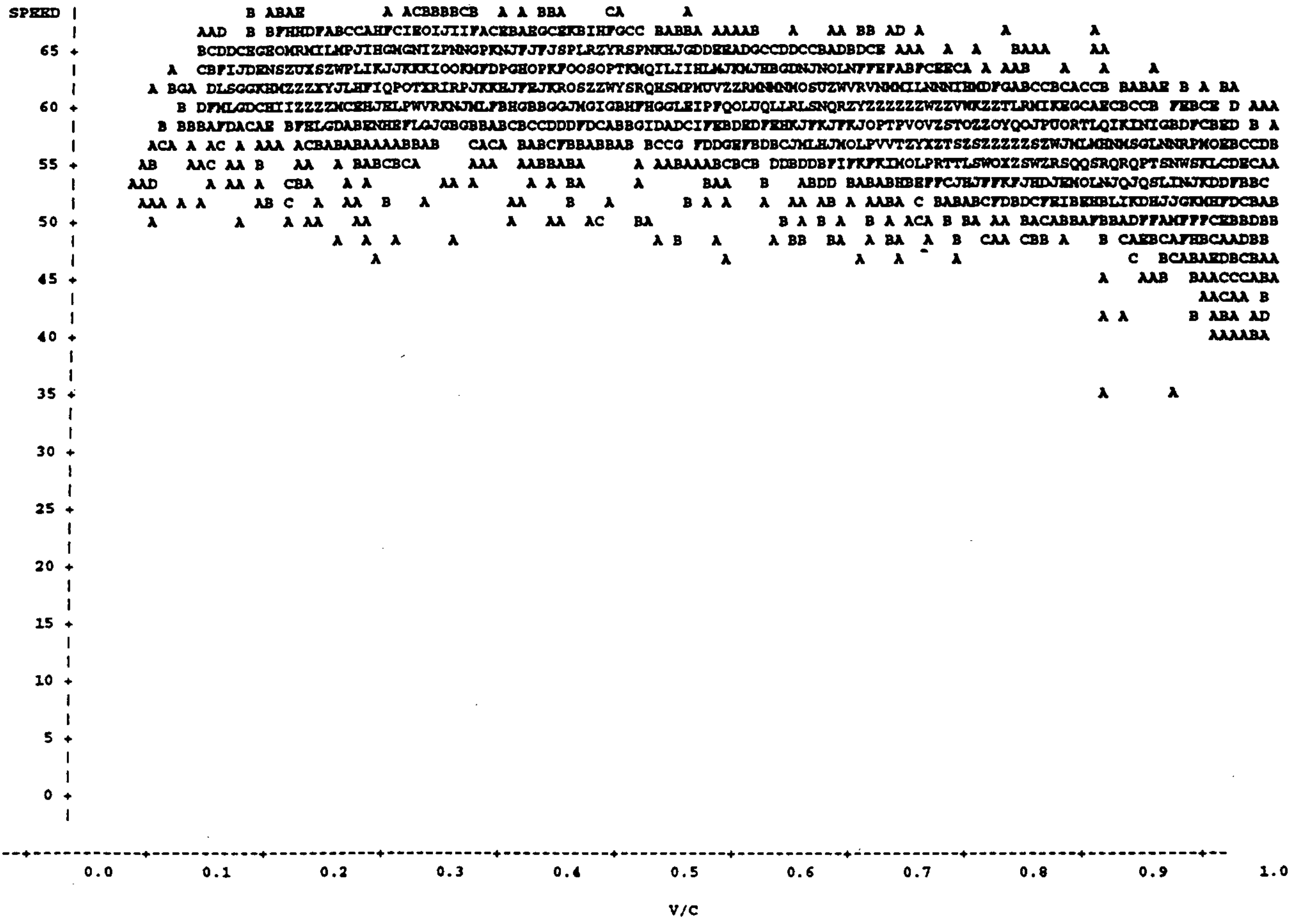
Figure 5-6. Uncongested speeds for volumes less than capacity from I-4 in Orlando.



NOTE: 204 obs hidden.

Figure 5-7. Uncongested speeds for volumes less than capacity from I-25 in Denver.

imprecise. Example: 0.44 is selected using 0.5 as the mean (from the first step) and an 8.5 percent coefficient of variation (on the basis of Table 5-3).

3. Put the sampled value of V/C into the BPR equation to get an initial value of speed. Example: 59.7 mph, assuming a free-flow speed of 60 mph, is the predicted speed using V/C = 0.44.
4. Use the 90 percent confidence bounds from Table 5-4 to develop an error distribution around the initial BPR speed. Randomly sample from this distribution to select a new speed. Example: randomly sample from a normal distribution with a mean of 59.7 mph (from Step 3) and a coefficient of variation of 6 percent (on the basis of Table 5-4) to produce a speed estimate of 55.7 mph.
5. Repeat Steps 1 through 4 until a complete distribution of final speeds is produced. The results are summarized in Table 5-5.

The final errors associated with estimating speeds on individual free-flow freeway segments is approximately 6 percent. However, the MOBILE5a model is rarely used to analyze individual highway segments; a more typical application involves speed estimation for roadway segments of a given functional class, with each segment including many links. When the errors are accumulated in this way, a dampening effect on the overall variation occurs: estimates might be high for one link but low for another. Formally, the equation for estimating the variance across a set of independent links is as follows:

$$\text{Var} = \{s_1^2 + s_2^2 + \ldots + s_n^2\}/n^2 \qquad (1)$$

where:

s_n^2 are the variances of speeds on individual segments or network links and
n is the number of links.

For this application, the variances of all the links of a functional class are the same and are calculated by assuming an average speed of 55 mph and a coefficient of variation of 6 percent (from above); this yields a link speed variance of

TABLE 5-4 Regression results from fitting the BPR equation

Location	R^2	Overall F-Value	V/C Coefficient	Standard Error of Estimate	Lower 95% CI at V/C = 0.7	Upper 95% CI at V/C = 0.7
Denver	0.573	10,262*	0.216	0.00213	54 mph	65 mph
Orlando	0.325	12,452*	0.156	0.00140	50 mph	60 mph

*Significant at alpha = 0.01.

10.9. To estimate the typical numbers of links in an urban network, data from FHWA's HPMS for 1993 were used (Table 5-6). The average number of links from Table 5-6 is then used in Equation 1 for n along with the calculated variance of 10.9 (all links). A resulting estimate of network speed precision for free-flow freeway segments is then based on an average speed of 55 mph and a coefficient of variation of 1 percent (i.e., a standard deviation of 0.55 mph). This is a relatively tight error range, especially given the widely held problems with network models; however, the following three points must be kept in mind:

- For free-flow freeways, speed is relatively insensitive to volume over a wide range of volumes as exhibited in the BPR curve, the Orlando and Denver freeway data, and the 1994 *Highway Capacity Manual*. This implies that precise estimates of volumes and capacities are not needed for these conditions.
- The averaging effect over many links eliminates much of the variation.
- This analysis assumes that the speed estimates are perfectly accurate, that is, the mean of link speeds for this case is always 55 mph. This simplifying assumption was used to provide the best estimation possible in order to bound the problem. A more thorough discussion of the accuracy problem appears later in this chapter.

Congested (Forced-Flow) Freeways

Forced flow can occur on freeways if either a physical bottleneck exists or an incident blocks the travel way. The first case is referred to as *recurring congestion* because it can be expected to occur at the same location at roughly the same time. The second case is referred to as *nonrecurring congestion* because the location and time of incidents cannot be predicted. The most common physical bottlenecks are "lane drops" (where one or more lanes are reduced) and entrance ramps. For the purpose of this NCHRP study, only recurring congestion will be considered.

The onset of forced flow is characterized by an irregular stop-and-go driving pattern usually referred to by transportation engineers as queuing. The Orlando and Denver data were used to determine the speed of vehicles in queues by first identifying periods where at least 1 continuous hr of operation near capacity existed; this situation was defined to have speeds less than or equal to 30 mph and densities greater than or equal to 42 vehicles per lane-mile. (Both of these values are suggested by the *Highway Capacity Manual* to indicate traffic on the verge of forced flow.) For these continuous time periods, 5-min intervals with densities between 67 and 100 vehicles per lane-mile were selected as those where queuing occurred. (The reason for excluding observations with densities greater than 100 is that these are likely to be incident-related [nonrecurring] events.) The results of this analysis appear in Table 5-7. The results for both cities were remarkably similar, with average speeds in queues of approximately 15 mph and coefficients of variation around 30 percent. (This analysis does not address the length of time that queuing exists; however, this key condition is discussed later in this chapter.) The data in Table 5-7 are the average speeds of all vehicles measured for 5-min periods. Although substantial variation still exists in the 5-min averages, some variation is eliminated because of using average speeds of 5-min periods. Therefore, the coefficients of variation presented are

TABLE 5-5 Speed estimation errors on free-flow freeway segments

V/C	Avg. Predicted Speed (mph)	Coefficient of Variation
0.50	59.1	5.4%
0.60	58.5	5.2%
0.70	57.5	5.3%
0.80	56.2	5.5%
0.85	55.3	5.6%
0.90	54.2	5.9%
0.95	52.9	6.6%

TABLE 5-6 Average number of links in urban networks

Facility Type	Average Mileage	Assumed Links/Mile	Average No. of Links
Free Flow Freeway	30	1	30
Congested Freeway	26	1	26
Free Flow Arterial	192	3	576
Congested Arterial	35	3	105

TABLE 5-7 Speeds in queues from freeway field data

City	No. of 5-Minute Periods	Average Speed	Coefficient of Variation
Orlando (I-4)	2,407	16.1 mph	30.3%
Denver (I-25)	1,263	15.0 mph	33.3%

conservative estimates, that is, if all individual vehicle speeds could have been analyzed in one group, these would have been higher.

As with free-flow freeways, the results in Table 5-7 apply to speed estimation on individual freeway segments or network links. If the air quality analysis considers aggregation of links, then the same "averaging" effect of Equation 1 will occur. Applying the typical number of congested freeway links from Table 5-6, the range of results is defined by an average speed of 15 mph and a coefficient of variation of 6.5 percent.

Free-Flow and Congested Arterials

The research team did not have arterial data comparable to the Orlando and Denver freeways. Therefore, the research team used existing analytic methods and professional judgment to derive precision. The analytical methods selected were the arterial methodology from the *Highway Capacity Manual*, the NETSIM traffic simulation model, the original BPR curve, and the modified BPR curve ("BPR4" from Table 5-1). The comparison of these methods for free-flow conditions is presented in Table 5-8. (The *Highway Capacity Manual* methodology and NETSIM are in close agreement, while the BPR functions predict substantially higher speeds. This is because the *Highway Capacity Manual* and NETSIM consider signal density, a key determinant of arterial speeds. In fact, both the *HCM* method and NETSIM show that speeds are relatively insensitive to V/C level for the range studied. In the example cited, four signals per mile were included. If signal density is reduced to two per mile, the *Highway Capacity Manual* and NETSIM predict average speeds of around 30 mph. Because the BPR equation is insensitive to signal density, estimated speeds are the same.)

TABLE 5-8 Comparison of analytic methods for estimating speeds on free-flow arterials

V/C	HCM	NETSIM	BPR	BPR4
0.18	24.1 mph	20.2 mph	40.0 mph	40.0 mph
0.36	23.2 mph	18.3 mph	39.9 mph	39.3 mph
0.53	22.2 mph	17.3 mph	39.5 mph	37.1 mph
0.73	20.5 mph	15.2 mph	39.5 mph	31.2 mph

Assumptions: 4 signals per mile; C = 120 seconds; G/C = 50%; PHF = 1.00.

The comparison of the methods for congested conditions is shown in Table 5-9. Because NETSIM can consider the effects of queues from one hour to another, 3 successive hr of volumes greater than capacity were input; the remaining methods consider each hour in isolation. (The hourly input volumes and corresponding V/C ratios were taken from Cambridge Systematics (1994) and replicate field conditions.) The *Highway Capacity Manual* and NETSIM generally agree closely while the BPR functions still overestimate speeds; however, the effect of congestion in previous hours appears to be better accommodated by NETSIM—speeds steadily drop from Hour 15 through 19 as queues built up have not had time to dissipate. This effect is dramatic in Hour 19 where the observed V/C ratio is less than 1.0 but the speeds are still very low (7.9 mph) indicating the presence of a queue from the previous hours. This feature of NETSIM is desirable and leads to the conclusion that average speeds on arterials under congested conditions is around 8 mph, especially when demand volumes exceed capacity for more than 1 hr.

Because no field data on the variation in arterial speeds were obtained, professional judgment was used to estimate the coefficients of variation. For free-flow conditions, it was assumed that the average speed of vehicles on a "composite" arterial is 30 mph (on the basis of the above analysis). It was further assumed that the 95 percent confidence interval around this mean was ±10 mph, leading to a coefficient of variation of 17 percent. For congested conditions, the 95 percent confidence interval was assumed to be +5 mph around an 8 mph mean, leading to a coefficient of variation of 30 percent. Aggregating these distributions over an average urban network produces a mean of 30 mph and a coefficient of variation of 1 percent for free-flow arterials and a mean of 8 mph and a coefficient of variation of 5 percent for congested arterials. The results of the precision analysis are shown in Table 5-10.

ACCURACY OF SPEED ESTIMATES

The previous analyses relate only to the precision of speed estimation; that is, it is assumed that the average speeds are the true value and that some degree of variation exists around these mean values. The precision analysis shows that the

TABLE 5-9 Comparison of analytic methods for estimating speeds on congested arterials: average speeds

Hour	V/C	HCM	NETSIM	BPR	BPR4
15	0.93	17.0	13.9	36.0	22.9
16	1.04	11.9	12.2	34.0	18.4
17	1.08	9.9	6.0	33.2	17.0
18	1.06	10.9	4.8	33.6	17.7
19	0.88	18.3	7.9	36.7	25.0
20	0.73	20.5	16.0	38.4	31.2

Assumptions: 4 signals per mile; C = 120 seconds; G/C = 50%; PHF = 1.00.

TABLE 5-10 Final precision estimates for speed

Facility Type	Traffic Condition	Individaul Links		Network Summary			
		Mean	CV	# Links	Mean	CV	90% CI
Freeway	Free Flow	55 mph	6%	30	55 mph	1%	±2%
	Congested	16 mph	30%	26	16 mph	10%	±16%
Arterial	Free Flow	16 mph	30%	576	30 mph	1%	±2%
	Congested	8 mph	30%	105	8 mph	5%	±8%

variability of speed estimates for urban networks relatively free from congestion is reasonably small, although the variability for individual links is high. In addition to measuring precision (i.e., the "scatter" of repeated estimates as shown in Figure 5-1), it is important to consider the accuracy of the estimates. The previous analysis indicates that speeds in congested conditions are more difficult to estimate with precision and, as discussed below, are more difficult to estimate in an absolute sense as well. Much of the problem is related to estimating congestion effects over both space and time. For example, consider a typical network-model-based analysis where a series of links are represented. Once a queue has formed at a bottleneck, it may spread sufficiently far upstream to affect other links. However, in the network representation, only the link with the bottleneck is typically considered to be "congested." Further, if a queue builds up over the course of 1 hr, its effect will be felt in the succeeding hour(s) because the queue takes time to dissipate. Commonly used analysis techniques, such as those provided in the *Highway Capacity Manual*, do not consider this effect.

To study the effect of congestion on speeds over the course of a day, an experiment was designed using the FRESIM model, a microscale traffic simulation model for freeways.[1] A simple network was developed to represent a typical 8-mi segment of urban freeway (Figures 5-8 and 5-9). To simulate the occurrence of a bottleneck, a "lane-drop" strategy was used where three lanes were reduced to two and finally to one; the bottleneck is where the two lanes merge into one. The network was composed of eight 1-mi links, one downstream from the bottleneck location and seven upstream from the bottleneck. Hourly temporal distributions for each direction were taken from Margiotta et al. (1994) for a heavily congested situation as defined by an AADT/C ratio of 13.[2] The speeds predicted by FRESIM—thought to be a reasonable representation of actual conditions—were then compared to those derived by post-processing the same information with the original BPR curve for V/C ratios less than 1.0 and the BPR4 curve for V/C ratios greater than 1.0. This strategy is meant to represent standard practice, and the choice of the two BPR curves is based on the previous results. Speeds and VMT estimates for both peak and off-peak periods were also made. As defined by standard practice, the hours considered to be in the peak periods are those where volumes exceed capacity (8 a.m., 5 p.m., and 6 p.m. in this example). The definition of peak period for the FRESIM runs was determined by the number of hours where congestion occurred (4 hr in the morning and 4 hr in the afternoon for this example). For comparison to FRESIM, the BPR curves were applied to each of the eight links in the network for each hour and direction.

A major discrepancy exists between how this network is represented by travel forecasting models and their post-processors and how FRESIM handles it. The traffic assignment process of travel forecasting models does not simulate the effect of a traffic bottleneck adequately—it assigns traffic volumes past a bottleneck to the links downstream along the shortest paths. In reality, the traffic congestion is on the link immediately upstream from the bottleneck. FRESIM depicts the situation accurately. Another serious shortcoming of the travel forecasting model approach is that queuing (congestion) is assigned only to links where volumes exceed capacity. In reality, queues may spill back onto upstream links, even though their assigned V/C ratios are less than 1.0. Further, queues not only spill back in space but in time: queues that have built up in 1 hr will still be present later because they have not had time to dissipate. Because of its microscale nature, FRESIM adequately characterizes the formation and dispersion of queues over both time and space.

Ideally, the traffic assignment process of planning models should be able to simulate or reflect the effect of congestion and bottleneck situations; it has not so far because of the data and computer resources required. Improvements to the methods for assigning traffic to networks (e.g., the TRANSIMS effort sponsored by FHWA and various dynamic traffic assignment research) are in development and will provide more accurate speed and assigned volume estimates. Until then, the use of microscale traffic simulation models, such as NETSIM and FRESIM, produces the most reliable speed estimates. However, current data and computer limitations prohibit their use on an areawide basis (i.e., for an entire network). Therefore, their main usefulness would be as post-processors for selected high-interest corridors. Although

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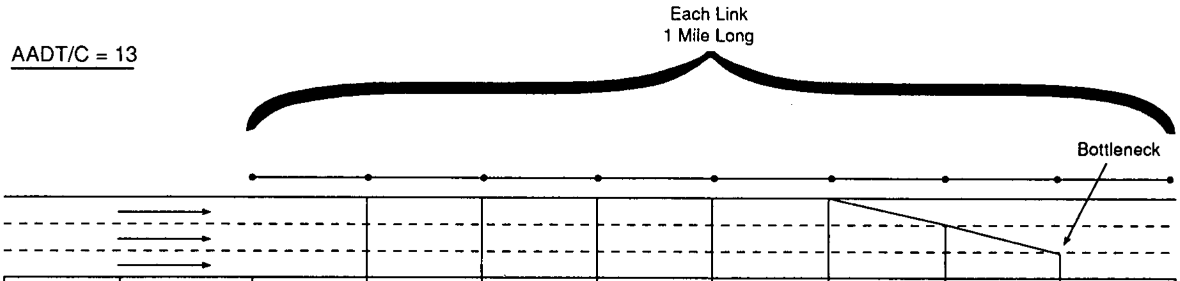
[1] Both NETSIM and FRESIM are termed "microscale" simulation models because they model the movements of individual vehicles second by second. The movement of each vehicle is determined by the characteristics of the highway network, driver behavior, and other vehicles in the traffic stream.

[2] AADT/C is the average annual daily traffic divided by the two-way capacity and is meant to be a *daily* measure of congestion. (V/C is an hourly concept.) An AADT/C of 13 is analogous to a four-lane freeway with 10 percent trucks and an AADT of 104,000 vehicles per day.



Hour	Target V/C*	Speed	Speed	Speed	Speed	Speed	Speed	Speed	Speed
16	0.94	59.0	58.5	58.5	58.5	58.4	57.1	51.3	53.3
17	1.05	58.8	58.4	58.2	58.2	58.0	55.0	24.5	50.9
18	1.01	59.0	58.5	58.5	58.4	55.8	10.8	13.0	51.2
19	0.87	59.3	59.0	58.9	58.8	47.7	5.8	13.2	51.4
20	0.65	59.4	59.2	59.2	59.1	58.8	15.2	15.3	52.3
21	0.52	59.2	59.1	59.1	59.0	58.9	58.4	55.3	54.8

*V/C of Bottleneck

AH 0595-002 SA

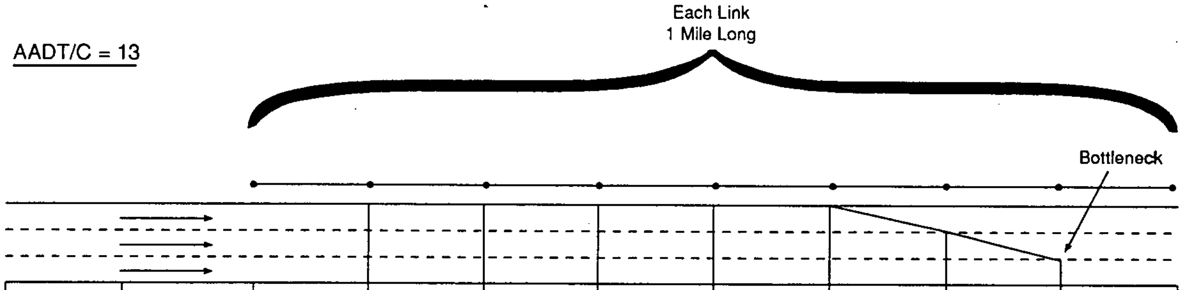
Figure 5-8. FRESIM experiment for afternoon peak direction.

field data would be preferable to simulation results for this type of analysis, none were available for this study. (The freeway surveillance data from Orlando and Denver used in the preceding subsection do not have sufficient detail to allow reliable analysis of either queue growth and dissipation or of estimating demand volumes at a bottleneck.)

The spillback phenomenon produces the dramatic differences shown in Table 5-11. The standard practice method seriously overestimates peak-period speeds and underestimates the duration of the peak periods (i.e., congestion). The results of FRESIM show that more than twice the VMT is exposed to lower speeds in comparison with the results of standard practice. When these data are used as inputs to MOBILE5a, major differences in emissions factors and total pollutants (emissions factors times VMT) result.

CONCLUSIONS CONCERNING THE ACCURACY AND PRECISION OF SPEED ESTIMATES

The precision analysis was undertaken to provide a measure of what the absolutely best estimates of speeds would be



Hour	Target V/C*	Speed	Speed	Speed	Speed	Speed	Speed	Speed	Speed
6	0.32	59.5	59.3	59.3	59.6	59.5	59.3	57.6	56.5
7	0.78	59.1	59.6	59.6	58.8	58.6	58.0	53.4	54.0
8	1.04	59.0	58.9	58.8	58.3	58.1	45.0	17.6	50.4
9	0.98	59.1	58.6	58.4	58.5	56.3	8.7	13.3	51.2
10	0.80	59.0	58.6	58.6	58.5	55.1	7.7	13.1	51.2
11	0.73	59.0	58.7	58.6	58.6	58.6	38.3	15.2	50.8
12	0.74	59.0	58.9	58.8	58.8	58.6	57.8	53.8	54.0

*V/C of Bottleneck

AH 0595-002 SA

Figure 5-9. FRESIM experiment for morning peak direction.

TABLE 5-11 Comparison of standard practice and FRESIM: peak period

Measure	Standard Practice	FRESIM
Speed	54 mph	38 mph
VMT Proportion	22%	48%
No. of Hours in Peak periods	3	8
VOC Emission Factor	1.51	1.75
CO Emission Factor	14.13	16.20
NO_x Emission Factor	3.57	2.81
Peak Period Grams of VOC (000)	148	375
Peak Period Grams of CO (000)	1,340	3,476
Peak Period Grams of NO_x (000)	352	603

Note: Total VMT for test network = 447,000 per day.

under ideal circumstances. The precision analysis assumed that speeds are derived from post-processing information from a travel forecasting model. Four types of links were considered—free-flow freeways, congested freeways, free-flow arterials, and congested arterials. Each link type was considered in isolation and, therefore, constitutes a near-ideal situation. The results of the precision analysis showed that under these conditions, individual estimates of link speed vary substantially. But, because of the averaging effect, the aggregation of link speeds—which is commonly done for areawide emission studies—produces more stable speed estimates.

Unfortunately, considering links in isolation is not practical in the real world. Except where congestion does not exist (e.g., small urban areas or off-peak hours), free-flow and congested links must be analyzed together. A hypothetical example underscored the shortcomings and potential inaccuracies in using travel forecasting models to estimate speeds. Shortcomings include

1. Inherent inaccuracies in predicted link volumes. Even when calibrating to base-year conditions, travel forecasting models typically do not replicate corresponding ground counts with a large degree of accuracy.
2. Variations in estimated link capacity. The V/C ratio is the key determinant of speeds on highway segments. Even if the *Highway Capacity Manual* methods are accurate, planners do not always follow *Highway Capacity Manual* methods. Typically, planners use short cuts to estimate capacities for network links because of limited data and the sheer effort required. It is common to use typical values of capacities for different functional classes of roads and number of lanes, ignoring many specific variations of roadway and traffic characteristics. This is especially true for arterials where only gross approximations of intersection capacity are used. Although these short cuts are adequate for performing travel forecasts, they hinder the speed estimation process for air quality planning. Further, even if perfect field data existed for each network link, strong evidence exists that the capacity actually varies from day to day, depending on conditions outside the control of the *Highway Capacity Manual* methodology. The most obvious factor influencing capacity variability is the daily variation in percent trucks. Other conditions not expressly considered also cause capacity to vary.
3. Difficulty in estimating free-flow-speeds. Free-flow speeds are the starting point of estimating speeds with any post-processor (as well as the traffic assignment process). Different assumptions about the free-flow speed will lead to different predicted speeds. For example, the speed data in Figures 5-6 and 5-7 suggest that the free-flow speed on Interstate 4 in Orlando is around 57 mph while on Interstate 25 in Denver it is around 62 mph. Not only does this show the variability in free-flow speeds because of local conditions, but both of these speeds are over the speed limit. Many planners would restrict the free-flow speed to 55 mph just to conform with their agency's operating policies. The setting of free-flow speeds on arterials is even more problematic.

The analytic methods used by post-processors are highly inaccurate for congested conditions. The typical application of a post-processor to a network considers links as individual entities, which is adequate for free-flow conditions; however, when volumes on a single link exceed capacity, repercussions develop on other links in the network that go unaccounted for by post-processors. First, there is the problem of "mislocating" the queue: the network model assumes that the bottleneck occurs at the extreme downstream end of the link where volumes exceed capacity—in reality, the queue is probably at the extreme upstream end. Second, queues from a single congested link usually spill back onto upstream links. Because post-processors consider only the V/C of individual links, free-flow speeds are predicted for these "spillback" links. Third, once a queue is formed by a bottleneck, its effects spread into adjacent periods. The travel forecasting framework in use usually considers the traffic in peak hours only. This is done by either forecasting peak hour volumes directly or first forecasting daily volumes and backing out the peak hour volumes with factors. However, the analysis presented in this section and substantial anecdotal evidence suggest that, in many urban areas, congestion lasts for several hours in both the morning and afternoon periods. Thus, the traditional "peak hour" has now become a "peak period" and speeds for the entire period must be considered.

The net effect of these problems is that speed estimates from travel forecasting models—the preferred platform for providing MOBILE5a inputs—are subject to considerable variation.

VARIABILITY IN VEHICLE (VMT) MIX ESTIMATES

Vehicle mix—the distribution of vehicles by weight and fuel type—is used by MOBILE5a to produce the composite emissions factors for air quality analyses. (This parameter is referred to as VMT mix in MOBILE5a.) Just as traffic counts are known to vary from day to day and hour to hour on a given section of a highway, the vehicle mix also changes. Classification of vehicles at selected locations routinely is done by state DOTs and some local transportation agencies to provide data for various planning applications. Classification counts traditionally were performed by visual observation but advanced equipment now allows automatic vehicle classification (AVC) to occur. AVC reduces the labor required and allows continuous counts to be taken. Many states use portable AVC equipment to perform short counts more efficiently and for longer periods than is practical using the visual method.

To examine the variability in the vehicle mix input to MOBILE5a, the research team obtained vehicle classification data from FHWA. These data are collected by the states and reported to FHWA annually as part of the Truck Weight Study program. Most of the data now comes from short counts (1 to 3 days) but, as more states switch to AVC, longer count durations will become common. The data are for both rural and urban highways, but only urban highways were used in this analysis. The data were screened so that only weekdays with complete 24 hr counts were used. Also, no more than 5 days at a particular site were included to avoid biasing the results. The characteristics of the final data set appear in Table 5-12. In all, 477 sites nationwide were used.

FHWA vehicle classifications are based on truck type (e.g., straight trucks and tractor trailer combinations) and axle configuration. This taxonomy is useful for pavement and safety studies and certain planning needs of transportation agencies. However, MOBILE5a's classifications are based on vehicle weight and engine fuel type, which are the key determinants of pollutant formation. Therefore, FHWA classifications must be translated into MOBILE5a classifications in order to convert field data into MOBILE5a inputs. (See Chapter 8 for a discussion of the conversion factors used.)

TABLE 5-12 Characteristics of urban vehicle classification sites, FHWA data

Characteristic	Number of Sites	Number of Days
State		
1. Arkansas	9	9
2. California	6	17
3. Colorado	19	23
4. Connecticut	14	16
5. Florida	2	7
6. Illinois	1	1
7. Kansas	42	58
8. Kentucky	15	17
9. Louisiana	15	15
10. Michigan	34	50
11. Missouri	4	4
12. Nebraska	11	22
13. Nevada	3	12
14. North Dakota	4	6
15. Rhode Island	16	24
16. South Carolina	39	60
17. South Dakota	2	9
18. Tennessee	8	8
19. Texas	68	102
20. Virginia	1	5
21. Wisconsin	6	11
22. Wyoming	1	1
	—	—
	320	477
Functional Class[1]		
1. Interstate	94	149
2. Freeway	42	77
3. Other Princ. Arterial	121	169
4. Minor Arterial	51	66
	—	—
	308	461

[1] Data for functional class catagories are incomplete.

The conversion factors were used here to convert the Truck Weight Study data into MOBILE5a vehicle type distributions. The results appear in Table 5-13. Substantial variation exists in the FHWA classification both between functional highway classes and within individual classes. For example, in the HDDV MOBILE5a category, the overall average from the field data (6.7 percent) is very close to the MOBILE5a default (6.2 percent). However, the average value masks the wide variation apparent between functional highway classes and among individual sites for a given class. A fourfold difference exists between urban interstate (10.6 percent of the traffic stream) and urban minor arterial (2.7 percent). Within a particular category, considerable variation exists from site to site. For example, the 90 percent confidence interval for HDDV vehicle type on urban interstates ranges from 3.1 percent to 27.2 percent. (In a normal distribution, the 90 percent confidence interval is defined by the 5th and 95th percentiles.)

To explore the effect of this variation on MOBILE5a results, risk-based sensitivity analysis was again used. Because vehicle mix is input as a distribution within a group rather than as a single value, it is not possible to use the variation of individual vehicle types shown in Table 5-13. Rather, the distributions from each of the 477 sites were used directly. That is, the distribution from Site 1 was used for the first MOBILE5a run, Site 2 data for the second, and so on. The total number of sites was increased to 1,000 by randomly sampling from the original 477 with replacement. A similar procedure was also used for urban interstates only. The results of running MOBILE5a with these different vehicle mix distributions are presented in Table 5-14. Little difference exists between the combined functional classes and the urban interstates only. If the 90 percent confidence interval is used, then the error bounds around each emission factor (all classes) are as follows:

TABLE 5-13 Urban weekday vehicle classification distributions from FHWA data

MOBILE5a Vehicle Type/ Functional Class	Default (Fraction)	FHWA Vehicle Classification Data				
		No. of Sites	Mean (Fraction)	Coefficient of Variation (Percent)	5th Percentile (Fraction)	95th Percentile (Fraction)
Motorcycles						
Interstate	0.007	148	0.001	178.768	0.000	0.007
Freeway	0.007	76	0.002	258.776	0.000	0.018
Other Princ. Arterial	0.007	171	0.003	240.993	0.000	0.011
Minor Arterial	0.007	66	0.003	296.757	0.000	0.009
Collector	0.007	16	0.006	109.910	0.000	0.022
Average or Total	0.007	477	0.002	257.363	0.000	0.009
LDGV						
Interstate	0.629	148	0.742	15.235	0.554	0.918
Freeway	0.629	76	0.743	12.935	0.573	0.893
Other Princ. Arterial	0.629	171	0.777	13.803	0.573	0.927
Minor Arterial	0.629	66	0.801	11.144	0.654	0.918
Collector	0.629	16	0.764	9.827	0.592	0.870
Average or Total	0.629	477	0.764	13.881	0.575	0.921
LDDV						
Interstate	0.003	148	0.009	15.235	0.007	0.011
Freeway	0.003	76	0.009	12.935	0.007	0.011
Other Princ. Arterial	0.003	171	0.009	13.803	0.007	0.011
Minor Arterial	0.003	66	0.010	11.144	0.008	0.011
Collector	0.003	16	0.009	9.827	0.007	0.011
Average or Total	0.003	477	0.009	13.881	0.007	0.011
LDGT1						
Interstate	0.182	148	0.112	67.435	0.002	0.229
Freeway	0.182	76	0.141	55.605	0.005	0.254
Other Princ. Arterial	0.182	171	0.136	61.200	0.003	0.287
Minor Arterial	0.182	66	0.133	61.224	0.031	0.283
Collector	0.182	16	0.137	67.366	0.023	0.326
Average or Total	0.182	477	0.129	62.584	0.003	0.259
LDGT2						
Interstate	0.084	148	0.007	50.213	0.002	0.013
Freeway	0.084	76	0.009	38.256	0.003	0.013
Other Princ. Arterial	0.084	171	0.008	50.846	0.002	0.016
Minor Arterial	0.084	66	0.008	47.381	0.003	0.014
Collector	0.084	16	0.007	61.968	0.001	0.016
Average or Total	0.084	477	0.008	48.699	0.002	0.014
HDGV						
Interstate	0.031	148	0.018	46.009	0.007	0.038
Freeway	0.031	76	0.018	39.662	0.009	0.032
Other Princ. Arterial	0.031	171	0.016	55.255	0.006	0.032
Minor Arterial	0.031	66	0.014	56.487	0.005	0.030
Collector	0.031	16	0.015	50.696	0.006	0.030
Average or Total	0.031	477	0.017	50.144	0.007	0.032

TABLE 5-13 *(continued)*

		FHWA Vehicle Classification Data				
MOBILE5a Vehicle Type/ Functional Class	Default (Fraction)	No. of Sites	Mean (Fraction)	Coefficient of Variation (Percent)	5th Percentile (Fraction)	95th Percentile (Fraction)
LDDT						
Interstate	0.002	148	0.004	61.459	0.000	0.008
Freeway	0.002	76	0.005	50.152	0.001	0.009
Other Princ. Arterial	0.002	171	0.005	57.604	0.001	0.010
Minor Arterial	0.002	66	0.005	56.772	0.002	0.010
Collector	0.002	16	0.005	65.878	0.001	0.011
Average or Total	0.002	477	0.005	57.911	0.001	0.009
HDDV						
Interstate	0.062	148	0.106	68.307	0.031	0.272
Freeway	0.062	76	0.074	88.934	0.019	0.233
Other Princ. Arterial	0.062	171	0.046	79.917	0.009	0.121
Minor Arterial	0.062	66	0.027	97.922	0.006	0.066
Collector	0.062	16	0.057	98.473	0.006	0.185
Total	0.062	477	0.067	92.890	0.009	0.213

Source: FHWA Truck Weight Study Data.

TABLE 5-14 Distribution of MOBILE5a composite emission factors due to variability in vehicle matrix

Functional Class	Emission Factor	Mean (gm/mile)	Coefficient of Variation	5th Percentile (gm/mile)	95th Percentile (gm/mile)
All Site Classes Combined	HC (VOC)	3.46	8.3%	3.01	3.91
	CO	36.51	13.8%	28.88	44.61
	NO_x	2.44	14.1%	1.93	3.00
Urban Interstate	HC (VOC)	3.40	7.9%	3.00	3.81
	CO	35.25	13.4%	28.56	42.50
	NO_x	2.34	13.9%	1.89	2.82

Source: Derived by combining the error distributions for assigned network volumes (from *NCHRP Report 255*) and empirical analysis of freeway capacity variability (from Orlando and Denver).

- HC: + 14 percent (Coefficient of Variation = 8.3 percent);
- CO: + 23 percent (Coefficient of Variation = 13.8 percent); and
- NO_x: + 23 percent (Coefficient of Variation = 14.1 percent).

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CHAPTER 6

AVERAGE SPEED UNCERTAINTY IN MOBILE EMISSION RATES

INTRODUCTION

In emissions modeling, as with all modeling, relationships between independent variables are represented by numerical formulas (or algorithms) within the model. Models are intended to be predictive. Thus, the internal algorithms are designed so that an engineer or policy analyst can input observed or estimated changes in independent variables (e.g., an increase in VMT) to estimate the changes in dependent variables (e.g., emission rates). However, the algorithms contained in models may or may not reflect true causal relationships. Too often, the algorithms are simply numerical representations of noted laboratory behavior from limited samples. Also, the uncertainty associated with using a statistically derived algorithm on the basis of limited samples or highly variable behavior often is not examined.

Because confidence intervals for emission rate model algorithms have not been reported in the literature, assessments of modeling uncertainty are based on professional judgment and sensitivity analysis (i.e., the degree to which a change in an independent variable affects the magnitude of the predicted, or dependent, variable). Although sensitivity analysis indicates which variables are likely to cause significant model output uncertainty, because of variation in the model input values provided, sensitivity analysis cannot reflect the modeling problems associated with poor statistical representation of the actual cause-and-effect relationships being modeled. Thus, emission modeling practitioners identify and rank uncertainty problems in their own order of importance, depending on their unique experiences. Further discussion of the uncertainty issues and of proposals to reduce uncertainty in emission rate models can be found in Bruckman and Dickson (1992), Gertler and Pierson (1991), Guensler (1993), Guensler and Geraghty (1991), Systems Applications International (1991), TRB (1992), and Wilson and Ripberger (1991).

Although current emission rate models do not provide confidence intervals around modeled outputs, these confidence intervals can be determined. By revisiting the data used to derive internal model algorithms and the data collected to determine input variables, the distributions from which the mean response algorithms and average input values were drawn can be determined. Once PDFs about each algorithm or input variable are determined, Monte Carlo techniques can be employed to estimate the uncertainty associated with model outputs.

Internal model algorithms can be replaced with equations or matrixes that represent the PDFs of the mean response. In the modeling effort, rather than using the mean response represented by the internal algorithm, the internal variable can be varied according to its probability distribution. When the model is run a sufficient number of times, the distribution of model outputs reveals the variability of model output as a function of the variability of the internal relationship employed. Of course, when multiple probability distributions are employed to represent several internal algorithms, the interactions between variables and the resulting uncertainty in those interactions can be examined as well.

Data inputs also can be replaced with modified inputs determined from equations representing the PDFs representing potential error in data measurement, estimation, or averaging. In this manner, analysts can examine the variability in model output as a function of the variability of internal variables, interactions, and input values.

This chapter discusses the results of the integration of Monte Carlo techniques into the existing EPA mobile source emissions rate model, MOBILE5a, to examine the uncertainty associated with using speed correction factors (SCFs) for the prediction of CO and HC emission rates. The components of uncertainty with respect to the emissions rate model and input variables are discussed first. The detailed description of the MOBILE5a SCF algorithms replaced by PDFs (as well as the methods originally employed by the regulatory agency to derive the mean response curves in MOBILE5a) is provided in Appendix A. The bootstrap methods used by the research team to derive the PDFs for the existing mean response curves and the input variables are discussed, followed by a description of the FORTRAN code changes that were made to represent the PDFs. The new Monte Carlo version of MOBILE5a (which will be called MOBILE5m) is run for various conditions designed to demonstrate how variance in internal algorithms (the modeled relationship between average speeds and emission rates) and associated input variables (average speed) establish the confidence bounds around mean prediction values. Finally, conclusions regarding the policy effects of using a model that can provide confidence intervals about projected values are drawn.

COMPONENTS OF UNCERTAINTY ANALYSIS

Model inputs and internal algorithms are subject to error. Measurement error, sample bias, and random error in the data employed as model inputs must be considered when the accuracy of model outputs is deemed important. Measurement error and sample bias in data collection can result in model input values that do not represent the universe of data. Random error coupled with a limited sample size can result in the use of a mean value, for an input variable, that does not well represent the average value for the entire population universe. Analysts acknowledge that model input values may be biased or uncertain. The effects of accuracy and precision of input data are typically examined through sensitivity analysis, where a range of input values are run to determine the effect that input error will have on output variability.

However, the accuracy of model outputs depends on the accuracy of input variables and the accuracy of internal model algorithms. Model outputs are 100 percent precise by definition, that is, given an invariant set of input variables, the model output will be the same every time the model is run. However, even if the input variables are 100 percent accurate, the model output will still be inaccurate when internal model algorithms yield inaccurate estimates of a desired parameter. The accuracy of these internal algorithms in turn depends on the accuracy and variability of the data employed to derive the internal algorithms.

Model Inputs

If the errors associated with data collected in the field are random and uncorrelated with variables of concern, errors are likely to cancel each other out. However, if the data and/or measurement errors are biased, the errors are less likely to cancel each other out. When a single input variable is used, that variable may be biased high or low. This bias introduced by error in the input variables affects the accuracy of model outputs. However, it is not possible to determine if the model inputs are biased high or low without collecting additional or improved data. The effect on the accuracy of model outputs can be considerable, but may be very difficult to predict.

Given that measured or modeled input variables are usually uncertain, it is wise to examine the potential effects that measurement errors can play in model outputs. The uncertainty effects associated with inaccuracy of input variables is relatively easy for analysts to test using sensitivity analysis. Sensitivity analysis is used to investigate the importance of correctly specifying model inputs. Typical sensitivity analyses reported in the literature (as presented in Chapter 5) examine changes in model outputs as a function of changes in model inputs. For example, the variation in model outputs might be examined as a function of a specified average speed estimate ±10 percent. By replacing the discrete input variable with values drawn from an appropriate PDF, the effect on model output can be examined. Each time the modified model is run with the varying input variable, the model will predict different outputs. The 50th percentile of the outputs from the modified model should approximately equal the output from the unmodified model, given sufficient trials (given a normal distribution of data and linear relationships, the 50th percentile would also equal the mean). Extreme value analyses are usually conducted as well to ascertain the maximum expected effects that input specification errors will have on outputs.

In theory, improving the accuracy of input variables should improve the accuracy of model outputs. Measured input variables may be biased, as a result of the measurement method employed. For example, a monitoring device may systematically undercount vehicles or a measuring technique may neglect to identify a small fraction of vehicle activity that produces significant emissions. The accuracy of input variables is the easiest component of the modeling process for analysts outside of the original model development process to improve on. New or improved methods for measuring or modeling input variables can lead to improved accuracy of input variable estimates. Hence, most model improvement studies focus on improving the accuracy of input variables. Every year, a few papers usually are presented at the TRB annual meeting proposing means to improve average speed estimates for various roadway classes.

However, if there is great uncertainty in an internal model algorithm, a point of diminishing returns can be quickly reached in the improvement of input variable accuracy. Guensler et al. (1994) demonstrated that improving the accuracy of average speed inputs to California's EMFAC7F model can have diminishing returns for low speeds, because the inherent uncertainty in the SCF algorithms employed in EMFAC7F overwhelms the error introduced by using uncertain average speed input values.

Model Algorithms

In algorithm development, data are collected and a statistical relationship is defined. During the statistical derivation of model algorithms, a mean value or mean response equation is determined from collected data and entered as a working equation in the model. For example, if one hundred 1990 model-year vehicles were tested on a standardized laboratory testing cycle, such as the FTP, the average emission rate (or mean sample response) might be entered into the model to represent the emission rate for all 1990 model-year vehicles. Similarly, the linear or curvilinear relationship between average speed and emissions may be included in an emissions model as a mean response algorithm.

Assuming that the test results are normally distributed, a standard error is associated with each mean response in the model. Confidence intervals bounding each mean response can be determined, given these standard errors. For example, if the mean response for the 100 hypothetical 1990 model-year vehicles is 0.50 grams per mile, and if the data are normally distributed with a standard error of 0.02 grams per mile, the 95 percent confidence interval for the mean response is a range from approximately 0.46 to 0.54 grams per mile (the range defined by the mean plus or minus twice the standard error). That is to say, one could be 95 percent sure that the average emission rate for 1990 model-year vehicles lies between 0.46 grams per mile and 0.54 grams per mile. Confidence interval analysis (based on re-analysis of the original data) can reveal how representative each mean response algorithm is likely to be (Guensler, 1993).

However, the average value or mean response curve derived depends on the data collected (and these data may or may not well represent the behavior of the actual universe of data from which the samples were drawn). Statistical methods yield inferences about relationships, but one can never quantify them to a certainty. For normally distributed data and a large representative sample, twice the standard error can be used to establish approximate bounds within which one could be 95 percent sure the true mean of the population resides. However, the true mean may still, by chance or poor sampling technique, lie outside of the estimated range.

Because the observed mean response in the data collected is only an estimate of the population mean, the use of the algorithm always provides a *systematic bias* in model outputs. One can be 100 percent certain that the average value included in the model is not exactly equal to the true average of the population. Hence, every time the average value is used, the predicted value is biased. The bias may be large or small, and high or low, depending on how well the causal relationships are modeled and how large and representative the laboratory sample was. Because it is impossible to know the true response, the actual direction and magnitude of model bias cannot be determined (without collection and analysis of the universe of data).

For algorithms already incorporated into models, the uncertainty associated with the internal model algorithms can be examined by re-analyzing the original data and statistically derived relationships. When a mean response from a laboratory sample is statistically derived, the PDF for the mean response can also be derived either through an assumption of normality and application of standard errors (Neter et al., 1990) or through a bootstrap resampling technique (Efron and Tibshirani, 1993). Either method permits the distribution of the mean to be estimated.

Confidence intervals around an internal model algorithm indicate that one is 95 percent sure that the true mean response for the sample universe lies somewhere between the uncertainty bounds (assuming a representative sample has been collected). Wide confidence intervals indicate a high potential for significant bias; analysts must live with this uncertainty. The wider the confidence interval bands, the more critical it is to obtain additional data and to ensure that a large representative sample is collected.

When mean response values and curves are employed in models, the precision of model outputs must be ignored. No matter how many times the model is run with a single set of input variables, the model will predict the same output. No information regarding model precision can be obtained in this manner. However, by replacing the mean response algorithms with appropriate PDF equations, the precision of the model output can be examined. Each time the modified model is run with a single set of input variables, the model will predict different outputs (although the averages of the outputs from the modified model will equal the outputs from the unmodified model).

MOBILE5A SPEED CORRECTION FACTORS

The EPA MOBILE5a model employs fleet average emission rates determined from laboratory test results. In the MOBILE5a model, the average baseline exhaust emission rates from vehicle emission tests on the FTP are compiled for each model year from a large sample of the vehicle fleet. The fleet emission rate is calculated from the model-year emission rates, weighted by the percentage of fleet composition for the group for each calendar year. To estimate emissions at speeds other than that under which the controlled laboratory testing was performed, baseline exhaust emissions are "corrected" within the model by applying a statistically derived emission ratio. This SCF represents the ratio between the average grams per mile emission rate for a given average speed and the grams per mile emission rate for an average speed of 19.6 mph (the average speed of the composite FTP testing cycle).

Figure 6-1 illustrates the modeled relationship between average speed and the CO emission ratio in the MOBILE5a model for modern fuel-injected vehicles equipped with three-way catalysts at low average speed respectively. These modern vehicles traveling at 10 mph are modeled as emitting roughly 1.5 times the CO emissions per mile as would be emitted on the hot-stabilized FTP subcycle (Bag 2). Thus, for a vehicle in this technology group, to predict the emission rate for average speeds that differ from that of the hot-stabilized FTP test, the baseline exhaust emission rate (FTP Bag 2) is multiplied by the SCF.

The mean response relationship between emissions and average speed (SCFs) is the focus of this study. The remainder of this section addresses the data and methods through which the MOBILE5a mean SCF response algorithm is replaced by a probability distribution. Re-analysis of data reveals that several statistical shortcomings exist in the original derivation of the mean response curve for SCFs (see Guensler 1993 for more details). However, the focus of the Monte Carlo analysis is to replace the existing mean response with an appropriate probability function. Violations of regression analysis assumptions in the original mean response curve derivation carry through into the probability distributions. Hence, the noted variability in the probability

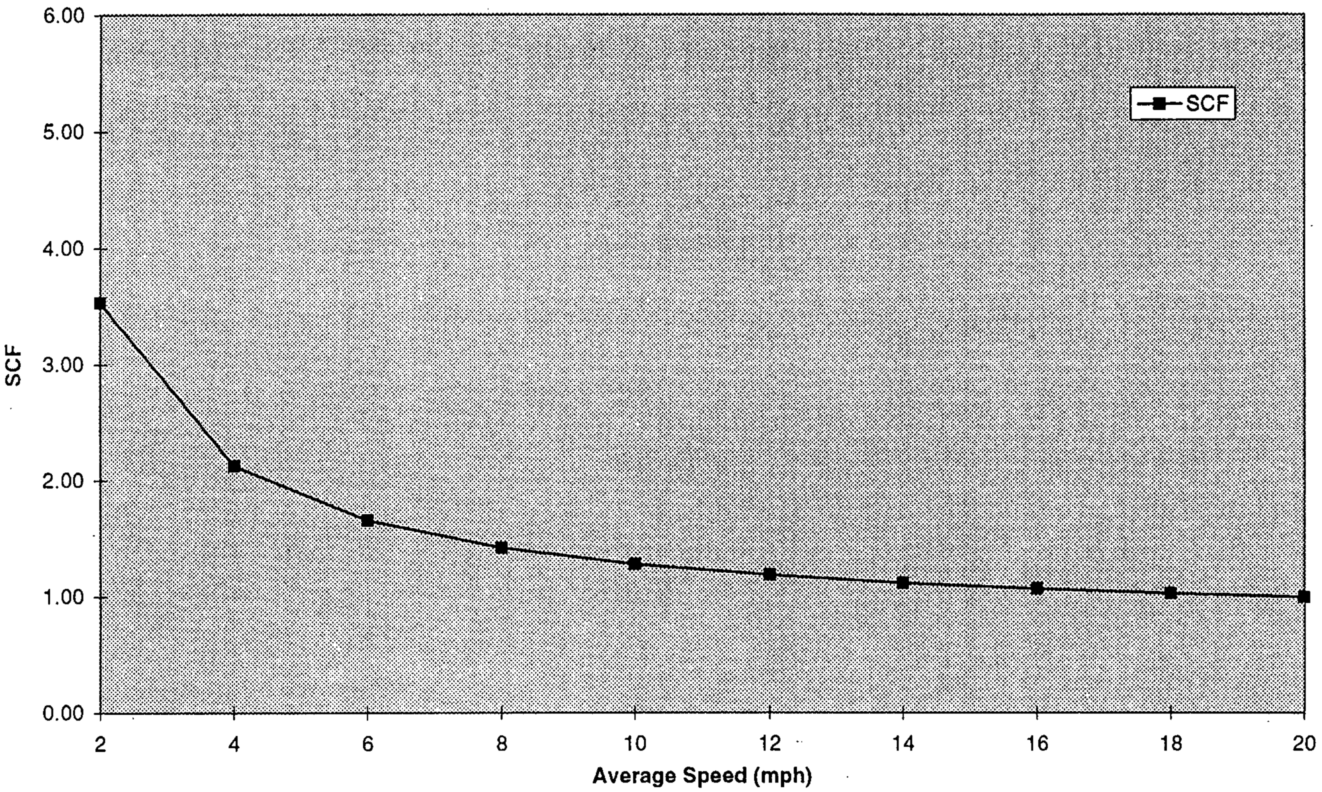

Figure 6-1. MOBILE5a speed correction factors (grams/mile)/(grams/mile) for CO: bootstrap regression results, low speeds.

distributions will also contain the contribution of errors introduced through flawed statistical methods.

The detailed methods employed to develop the MOBILE5a SCFs can be gleaned from the MOBILE4.1 (EPA, 1991), a publication by Energy and Environmental Analysis (EEA) (1991), and the MOBILE5a users manual (EPA, 1994a). The regression functional form reported by the EPA (1991) coupled with the data screening criteria reported in a related work (EEA, 1991) best replicated MOBILE5a outputs when new SCF equations were generated through bootstrap analyses and incorporated into the MOBILE5a code. The test data, test cycle characteristics, data treatment, vehicle technology group characteristics, and regression analysis functional form are discussed in Appendix A.

BOOTSTRAP REGRESSION TECHNIQUES USED TO DEVELOP SCF PDFS

A bootstrap approach is a Monte Carlo-style simulation technique (Berg, 1992; Efron, 1982; Efron and Tibshirani, 1993; Vasu, 1979) used to estimate the upper and lower bounds of an analytical confidence interval and to develop a PDF for an analysis. The bootstrap is designed to overcome the difficulties of non-normal error distribution and unequal variance, conditions that prevent the appropriate use of standard error analysis. In bootstrap analysis, multiple samples are developed by random sampling *with replacement* from the sample domain (Efron and Tibshirani, 1993). Each data set contains the same number of total data points contained in the sample domain (in each subsequent sampling, some data may be selected multiple times while other data may not be selected at all). Typically, more than 1,000 simulations are run in bootstrap analyses.

In bootstrap regression analysis, the regression model is run for each bootstrap data set. The resultant beta coefficients from each analysis are used to predict the value of the dependent variable for a given set of independent variables. The mean response curve generated through standard regression corresponds very well to the 50th percentile result from the bootstrap regression analysis. The 95 percent confidence intervals for the predicted values of the regression function are approximately the bounds established by the 2.5 percent and 97.5 percent values for the given set of independent variables.

For analysis of the SCF algorithms, a BASIC program was written to develop 1,000 resampled data sets, calculate the average emission rate and baseline exhaust emission rate (Bag 2) results of the resampled data for each test cycle, estimate the regression intercept and slope coefficients for the regression function [$ER_S/ER_{BAG2} = B_0 + B_1(1/SPEED) + e$] and output predicted SCFs for average speeds in 2 mph increments to a file for later analysis. For each speed in 2 mph increments, the SCF results from the 1,000 runs are rank ordered to establish the PDF, where the probability of each predicted value is established as 1/1000.

Table 6-1 compares the CO mean response SCFs at various speeds from a single-pass least-squares regression analysis and from the 50th percentile of a 1,000-iteration bootstrap least-squares regression analysis of technology group 12 (1987 and later model-year fuel-injected vehicles equipped with three-way catalysts). Notice the close approximation of the bootstrap approach, deviating only by 4 percent at the most extreme end of the analytical range.

The PDF for SCFs is represented by the rank order matrix of probability, speed, and predicted SCF. Figures 6-2 through 6-4 illustrate the bootstrap regression results for EPA technology group 12 for low speeds, medium speeds, and for low and medium speeds combined. The rank order values at 2.5 percent and 97.5 percent represent the 95 percent confidence intervals around the mean response curve for any given average speed.

The derived probability distributions from bootstrap techniques always assume that a representative sample has been collected. Hence, any conclusions that can be drawn from the analytical results are still fundamentally limited by this assumption.[1] When problems with sample representativeness are noted, the only solution is to gather additional vehicle data to fill the noted gaps in the data set.

TABLE 6-1 Predicted CO SCFs for tech group 12 vehicles, standard regression analysis mean response and bootstrap regression analysis median response

Average Speed	Standard Regression	Bootstrap Regression	% Difference
2	5.07	5.08	0.00
4	2.80	2.81	0.00
6	2.05	2.05	0.00
8	1.67	1.67	0.00
10	1.44	1.45	0.00
12	1.29	1.29	0.00
14	1.19	1.19	0.00
16	1.10	1.10	0.00
18	1.04	1.04	0.00
20	0.99	0.99	0.00
22	0.89	0.90	0.00
24	0.82	0.02	0.01
26	0.76	0.76	0.01
28	0.70	0.71	0.01
30	0.66	0.67	0.01
32	0.62	0.63	0.02
34	0.58	0.59	0.02
36	0.55	0.56	0.02
38	0.52	0.54	0.03
40	0.50	0.51	0.03
42	0.47	0.49	0.03
44	0.45	0.47	0.03
46	0.43	0.45	0.04
48	0.42	0.43	0.04

Note: The 20-mph breakpoint divides low-speed activity and medium-speed activity. This validation run was prepared prior to normalization; thus, the noted SCFs differ from the normalized SCFs presented in the figures.

MONTE CARLO MODELING

A Monte Carlo adaptation of a model is the substitution of PDFs for their associated mean response algorithms already in the model. During each model run, rather than using the mean response, a value from the mean response probability matrix is employed. For each variable represented by a PDF, a random uniform number (a decimal between 0 and 1 selected with equal probability) is input into the mean response PDF matrix to provide a variable value. The Monte Carlo adaptation of the model is then run thousands of times using FORTRAN "do loops." The median of all values pulled from the PDF for multiple model runs will equal the mean response normally included in the model. When the number of Monte Carlo model runs is sufficiently large, the distribution of the Monte Carlo can be used to approximate the standard error bounds of the mean output response of the original model. That is, an analyst can be 95 percent sure that the output lies between the 2.5 percent and 97.5 percent rank order model outputs. The distinct advantage of the Monte Carlo technique is that when model results are output to a file, the confidence bounds that surround predictions can be determined directly. The integration of the SCF probability distributions into MOBILE5a is discussed in detail in Appendix A.

Once the probability distribution matrixes for SCFs were integrated into the MOBILE5a model, an internal do loop was established to run each requested analysis 1,000 times.[2] The MOBILE5m model retains and prints the 50th percentile from each multiple Monte Carlo model run, along with the 2.5th percentile and the 97.5th percentile that compose the 95 percent confidence interval of the predicted value.

Average Speed Data Input in MOBILE5m

Because the Monte Carlo model will run thousands of times, varying the SCF for any given average speed, it was also desirable to provide the capability to vary average speed input to the model. In this way, the variation associated with uncertainty in average speed input and interaction of this variation with SCF variation could also be examined. MOBILE5m, after reading the initial input file for analysis, will (on request) vary the input value of the average input speed in accordance with a mean and standard deviation of average speed provided by the modeler each time the model is run internally. When the average speed is allowed to vary, the model employs the following function for each iteration:

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[1] The emission rate correction factors were not derived from a representative vehicle fleet (Smith et al., 1994).

[2] The appropriate number of runs that should be taken under a Monte Carlo approach can be determined by steadily increasing the number of runs until the increase in runs has no significant effect on the 95 percent confidence intervals of the output results (Efron and Tibshirani, 1993).

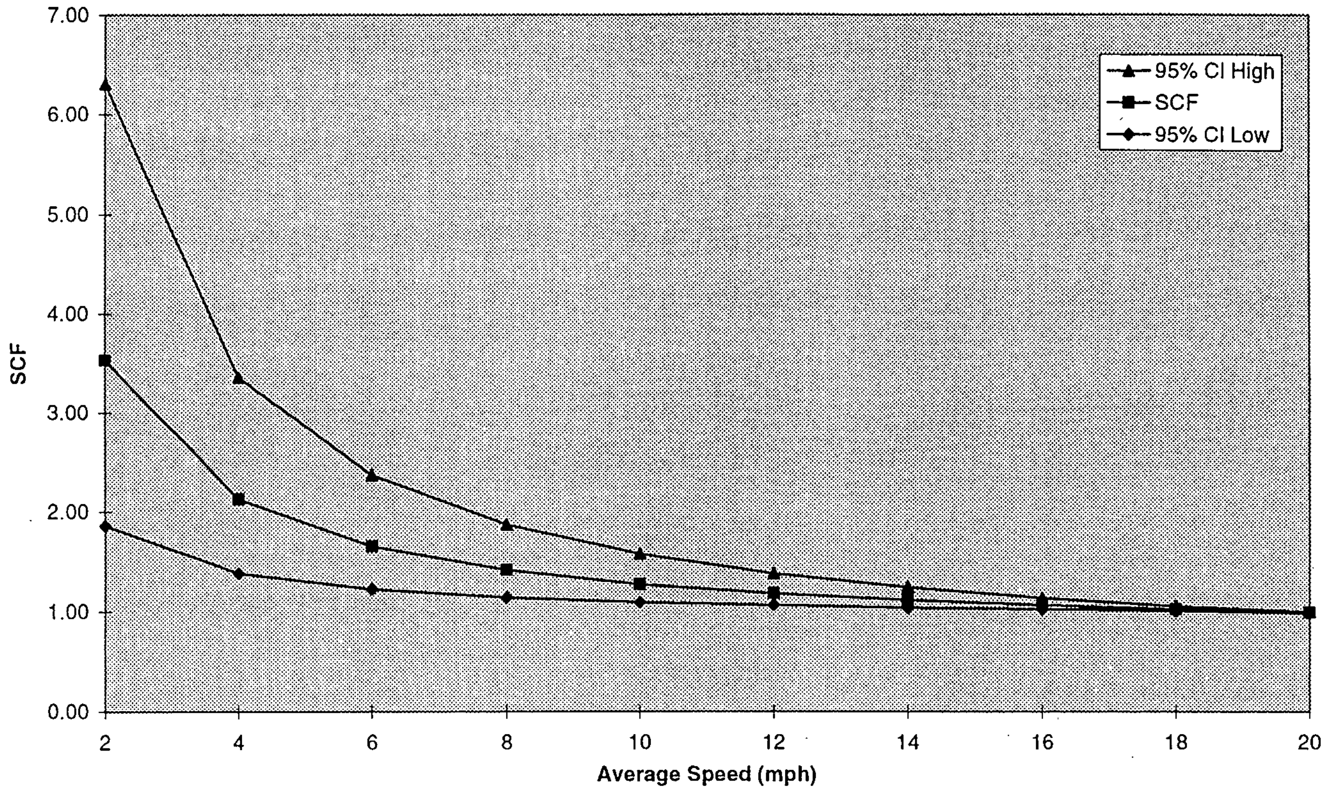

Figure 6-2. MOBILE5a speed correction factors (grams/mile)/(grams/mile) with confidence bounds for CO: bootstrap regression results, low speeds.

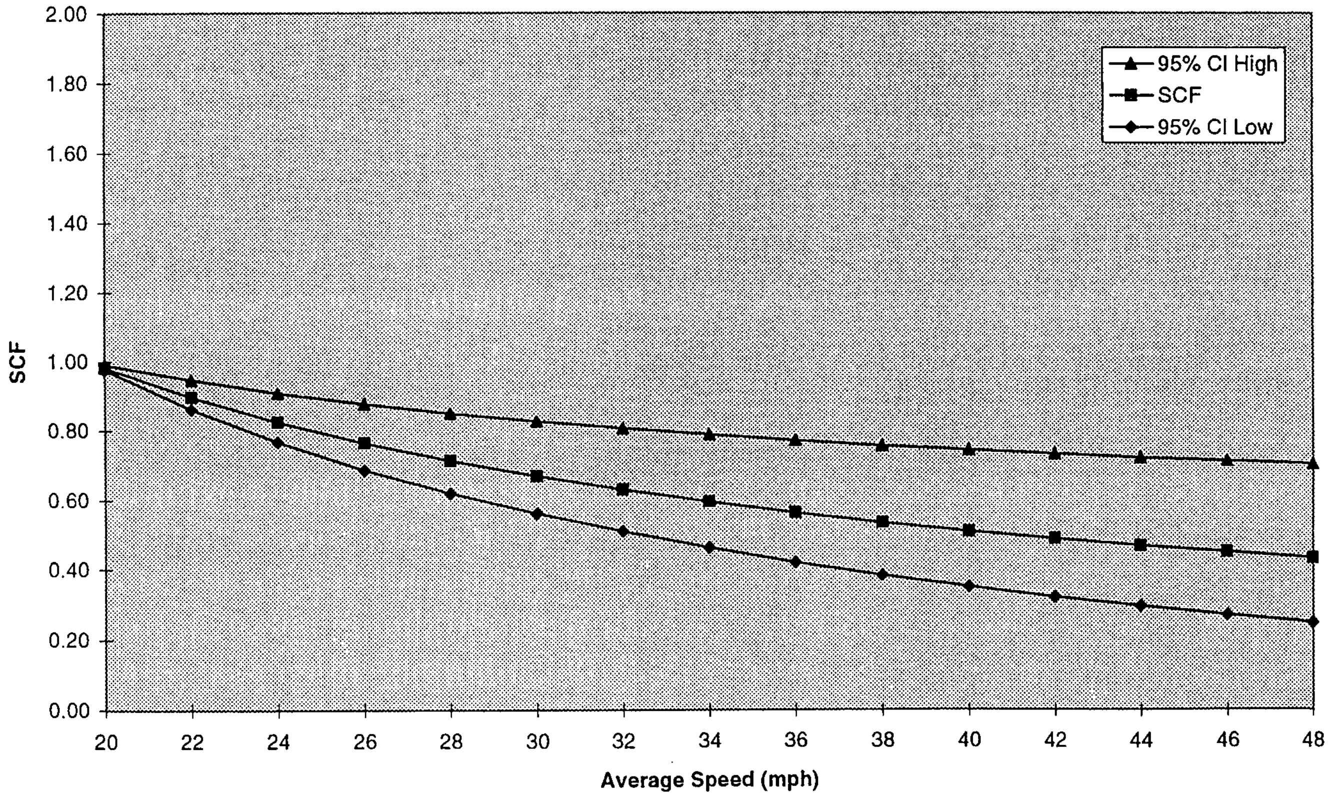

Figure 6-3. MOBILE5a speed correction factors (grams/mile)/(grams/mile) with confidence bounds for CO: bootstrap regression results, medium speeds.

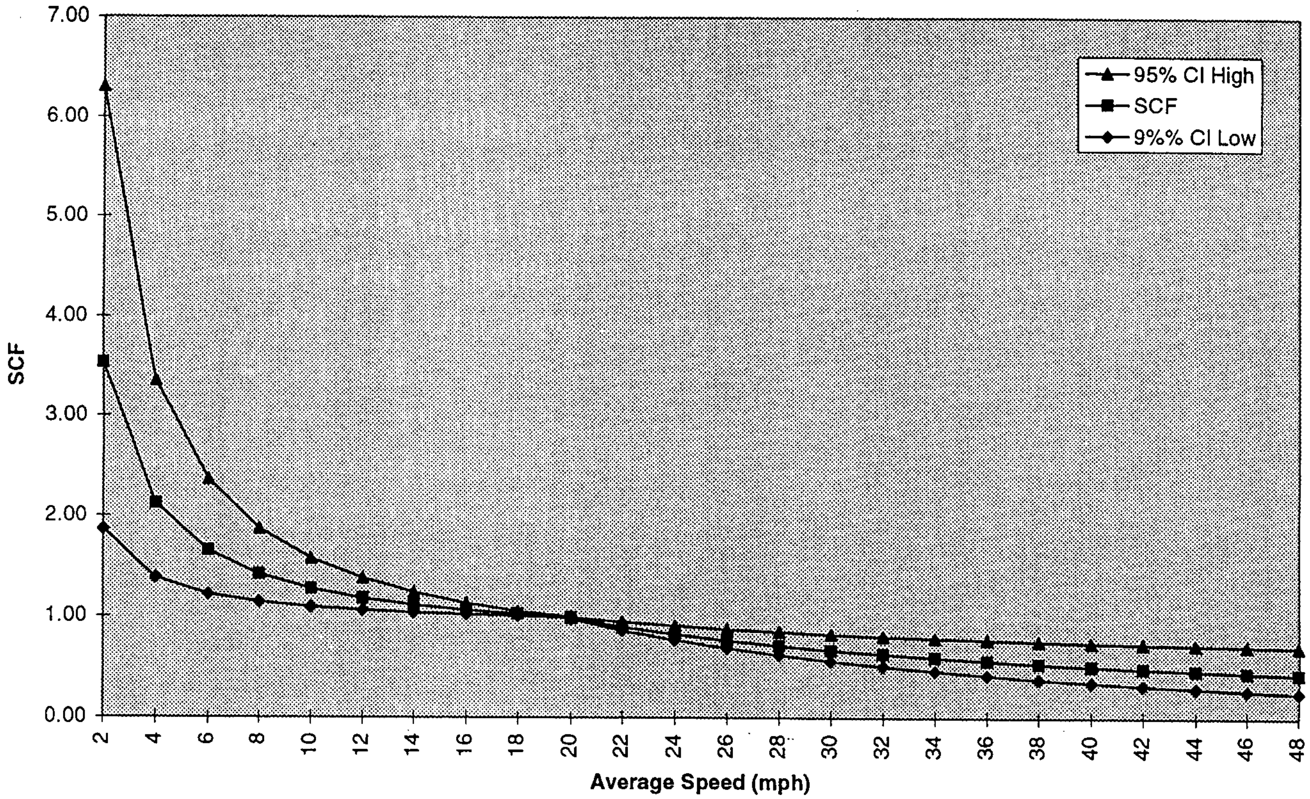

Figure 6-4. MOBILE5a speed correction factors (grams/mile)/(grams/mile) with confidence bounds for CO: bootstrap regression results, low and medium speeds.

New Average Speed =
Input Average Speed + (Random Gaussian Number · Standard Deviation) .

Four facility types and LOS combinations were identified by the research team as being of interest for model evaluation (Table 6-2). The average speeds and standard deviations for these facility- or congestion-level groups were determined through statistical analysis by other team members (Margiotta, 1995) and were provided to the authors for use as variables in the MOBILE5m runs.

Each of the facility type and LOS combinations was examined using the MOBILE5m model, once with the average speed input held constant and once with the average speed input allowed to vary as a function of the mean and standard deviations.

TABLE 6-2 Facility types and level of service combinations examined by MOBILE5m

	Uncongested		Congested	
Facility Type	Average Speed (mph)	Standard Deviation (mph)	Average Speed (mph)	Standard Deviation (mph)
Freeway	55	0.55	16	1.60
Arterial	30	0.225	8	0.4

ANALYTICAL RESULTS

This section of the report examines two sets of analytical results: (1) the variability of the SCFs derived from the bootstrap analysis, and (2) the variability of MOBILE5m model output, based on Monte Carlo simulation of four different facility type and LOS combinations, both with and without variation in input speed.

Speed Correction Factors

When confidence intervals are examined for the SCFs in MOBILE5a, it becomes clear that modeled estimates lie between very wide uncertainty bounds. Tables 6-3 and 6-4 contain the CO SCFs and confidence intervals for 1987 and later model-year fuel-injected vehicles. Tables 6-5 and 6-6 contain the corresponding factors and intervals for HC. In Table 6-3, one can be 95 percent confident that the CO SCF for this technology group at 10 mph lies between 1.1 and 1.6 (this SCF uncertainty will play a significant role in the uncertainty for hot- and cold-start emissions). At 10 mph, and most

TABLE 6-3 Speed correction factors with 95% confidence interval for CO, 1987 and later model year fuel injected vehicles (three-way), technology group 12

Low Speeds				Medium Speeds			
Average Speed	SCF 95% Low	Mean SCF	SCF 95% High	Average Speed	SCF 95% Low	Mean SCF	SCF 95% High
2	1.86	3.53	6.31	20	0.97	0.98	0.99
4	1.38	2.12	3.35	22	0.86	0.89	0.94
6	1.22	1.65	2.37	24	0.77	0.82	0.90
8	1.14	1.42	1.87	26	0.69	0.76	0.87
10	1.09	1.28	1.58	28	0.62	0.71	0.84
12	1.06	1.18	1.38	30	0.56	0.66	0.81
14	1.04	1.12	1.24	32	0.51	0.62	0.79
16	1.02	1.06	1.14	34	0.46	0.59	0.77
18	1.01	1.03	1.05	36	0.42	0.56	0.75
20	0.99	0.99	1.00	38	0.38	0.53	0.74
				40	0.35	0.50	0.72
				42	0.32	0.48	0.71
				44	0.29	0.46	0.70
				46	0.27	0.44	0.69
				48	0.24	0.42	0.68

other speeds, the inherent uncertainty associated with using the SCF is much larger than the error introduced by 10 percent errors in average speed measurement. That is, the improvement in SCF prediction accuracy resulting from improved speed measurements will be completely overwhelmed by the remaining uncertainty associated with the use of SCFs.

The confidence intervals are fairly wide for the SCFs because the emission response to changes in the test cycles is highly variable across the vehicle fleet. When changing from one test cycle to another, some vehicle emissions may increase by as much as two orders of magnitude, while other vehicle emissions may decrease by as much as two orders of magnitude (Guensler, 1993; Guensler et al, 1994; Washington, 1994). Hence, minor changes in the selection of vehicles for testing can result in significant changes in the average emission response derived through regression analysis. Further evidence of the variability is provided in Guensler et al. (1994) which demonstrated that vehicle test results are fairly well correlated across similar cycles, but

TABLE 6-4 Speed correction factors with 95% confidence interval for CO, 1987 and later model year fuel injected vehicles (three-way), technology group 13

Low Speeds				Medium Speeds			
Average Speed	SCF 95% Low	Mean SCF	SCF 95% High	Average Speed	SCF 95% Low	Mean SCF	SCF 95% High
2	2.49	10.03	91.33	20	0.97	0.98	1.00
4	1.66	5.00	41.03	22	0.85	0.90	1.01
6	1.38	3.33	24.27	24	0.74	0.83	1.02
8	1.25	2.49	15.88	26	0.65	0.77	1.03
10	1.16	1.99	10.85	28	0.57	0.72	1.04
12	1.11	1.65	7.50	30	0.51	0.68	1.05
14	1.07	1.41	5.10	32	0.45	0.64	1.05
16	1.04	1.23	3.31	34	0.40	0.61	1.06
18	1.02	1.09	1.91	36	0.35	0.58	1.06
20	0.79	0.98	1.00	38	0.31	0.55	1.06
				40	0.28	0.53	1.07
				42	0.24	0.51	1.07
				44	0.21	0.49	1.07
				46	0.18	0.47	1.08
				48	0.16	0.45	1.08

TABLE 6-5 Speed correction factors with 95% confidence interval for HC, 1987 and later model year fuel injected vehicles (three-way), technology group 12

Low Speeds				Medium Speeds			
Average Speed	SCF 95% Low	Mean SCF	SCF 95% High	Average Speed	SCF 95% Low	Mean SCF	SCF 95% High
2	4.27	7.51	13.02	20	0.98	0.98	1.00
4	2.45	3.88	6.33	22	0.87	0.91	0.98
6	1.84	2.68	4.10	24	0.78	0.86	0.97
8	1.54	2.07	2.98	26	0.71	0.81	0.96
10	1.36	1.71	2.31	28	0.65	0.76	0.95
12	1.24	1.47	1.87	30	0.59	0.73	0.94
14	1.15	1.30	1.55	32	0.54	0.69	0.93
16	1.08	1.17	1.31	34	0.50	0.67	0.93
18	1.03	1.07	1.12	36	0.46	0.64	0.92
20	0.97	0.99	0.99	38	0.43	0.62	0.92
				40	0.40	0.60	0.91
				42	0.37	0.58	0.91
				44	0.35	0.56	0.91
				46	0.32	0.55	0.90
				48	0.30	0.53	0.90

not well correlated across dissimilar cycles. Low-speed cycle results are well correlated to low-speed cycle results, but poorly correlated to higher average speed cycle results, and emission test results for vehicles at the highest speed cycle are not well correlated to the results for other cycles.

The variation noted in the MOBILE5a SCFs is less than the variation noted in the EMFAC7F SCFs (Guensler, 1993; Guensler, et al., 1994) for medium speeds. The effect of poor correlation between testing cycles is downplayed in the MOBILE5a SCF variation as a result of the modeling approach taken in MOBILE5a where separate SCF modeling regimes are employed for low and medium average speeds. By dividing the SCFs into two speed regimes, the regression analyses are not required to employ all of the data, reducing the natural variability in the average response curve. However, as noted earlier, the normalization of SCFs to 19.6 mph is problematic—correction through normalization results in analytical bias in the mean response curve.

TABLE 6-6 Speed correction factors with 95% confidence interval for HC, 1987 and later model-year fuel-injected vehicles (three-way + oxidation), technology group 13

Low Speeds				Medium Speeds			
Average Speed	SCF 95% Low	Mean SCF	SCF 95% High	Average Speed	SCF 95% Low	Mean SCF	SCF 95% High
2	4.43	10.36	31.96	20	0.97	0.98	0.99
4	2.52	5.15	14.72	22	0.85	0.89	0.96
6	1.88	3.41	8.97	24	0.75	0.82	0.93
8	1.56	2.54	6.10	26	0.67	0.75	0.90
10	1.37	2.02	4.38	28	0.59	0.70	0.88
12	1.25	1.67	3.23	30	0.53	0.65	0.86
14	1.16	1.43	2.41	32	0.47	0.61	0.85
16	1.09	1.24	1.79	34	0.42	0.57	0.83
18	1.03	1.09	1.31	36	0.38	0.54	0.82
20	0.93	0.98	0.99	38	0.34	0.51	0.81
				40	0.31	0.49	0.80
				42	0.28	0.46	0.79
				44	0.25	0.44	0.78
				46	0.22	0.42	0.78
				48	0.20	0.40	0.77

TABLE 6-7 Comparison of MOBILE5a-predicted and MOBILE5m-predicted (50th percentile) CO and HC running exhaust emission rates for scenarios examined

		Uncongested Conditions		Congested Conditions	
		MOBILE5a	MOBILE5m	MOBILE5a	MOBILE5m
CO					
	Freeway	11.06	11.06[1]	26.20	24.61
	Arterial	15.78	16.37	46.32	40.37
HC					
	Freeway	0.83	0.83[1]	1.97	2.05
	Arterial	1.19	1.23	3.42	3.94

[1] **The results for the uncongested freeway conditions (55 mph, 0 mph standard deviation) are exactly the same as the outputs from MOBILE5a because the high speed correction factors are not replaced by bootstrap-derived SCFs.**

Facility Type and LOS Analyses

The variability of MOBILE5m model output was examined on the basis of Monte Carlo simulation of four different facility type and LOS combinations (freeway/arterial, uncongested/congested) and is presented in the Table 6-2. The MOBILE5m model was run for these average speed conditions both with and without variation in the input average speed. The outputs from the eight individual model runs are presented in their entirety in Appendix B. A sample MOBILE5m input file for the runs is contained in Appendix C. The median MOBILE5m Monte Carlo responses are compared to the MOBILE5a outputs in Table 6-7.[3]

For all pollutants and speed and congestion groups, the MOBILE5m predictions closely replicate the MOBILE5a corrections. The MOBILE5a predictions fall well within the confidence bounds for the MOBILE5m analyses. An extremely close match is theoretically possible, as noted in Table 6-1, provided that the same regression functional form and data are employed in both analyses and that sufficient data are included in the original sample. These predictions should not be expected to match perfectly, however, because there are still unanswered questions regarding which data were actually employed in the EPA analyses to derive the SCFs and how the technology group regression coefficients were actually weighted to prepare the internal SCF algorithms in MOBILE5a (see Appendix A).

The results of the MOBILE5m runs for the various facility types and LOS combinations examined as part of this study are presented in Tables 6-8 (standard deviations of speeds equal to zero) and 6-9 (average speeds allowed to vary according to given standard deviation). Tables 6-8 and 6-9 provide the 95 percent confidence interval associated with the average output value. That is, one is 95 percent sure that the average value of the emission rate for each condition is bounded by the values indicated at 2.5 percent and 97.5 percent. No confidence bounds are reported for the uncongested freeway analysis when standard deviation of speed is set to zero because the standard MOBILE5a SCFs are employed (speed >48 mph).

The clearest effect of the MOBILE5m analytical results is that the use of SCFs within the model results in significant uncertainty in emission rate output. The confidence intervals are very wide, especially for CO. Given the large proportion of 1987 and later model-year vehicles in the current fleet, it is not surprising that the uncertainty associated with the SCFs, noted in Figures 6-2 through 6-4, and represented by probability distribution matrixes in the MOBILE5m model, are evident in the outputs of the MOBILE5m model.

The effect of the standard deviation of input average speeds on overall emission rate uncertainty is much smaller than that of the internal SCFs. The effect on the width of the confidence bounds is almost imperceptible. This indicates that one cannot be certain that improving average speed estimates for input to the MOBILE5a model under these conditions will lead to significant improvements in the accuracy of model outputs.

Furthermore, the nonlinear nature of the SCFs employed in the model results in an additional inherent emission rate bias. In the low-speed regime, for every average speed that is 1 mph less than the average, the emission rate increase is greater than the emission rate decrease associated with an average speed that is 1 mph less than the average. Hence, the MOBILE5a emission rate predicted from the average of all average vehicle speeds will be slightly smaller than the aver-

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[3] The results presented are for the normalized SCF model employed by the EPA in MOBILE5a. As discussed in Appendix A, the normalization effort creates a problem in terms of interpreting the mean response SCF and confidence bounds. The predicted low SCFs are adjusted by the predicted composite FTP correction factor (at 19.6 mph). Hence, if the predicted composite FTP was greater than 1, the predicted low or high SCF in the normalized model is smaller than the least-squares model actually predicts. Conversely, if the predicted composite FTP was less than 1, the predicted low or high SCF in the normalized model is higher than the least-squares model actually predicts. The same relationship is true with the predicted confidence bounds that arise through the bootstrap analyses. To ensure that the SCF equation predicts 1.0 at 19.6 mph (which also lies outside the data domain used to develop the low SCFs), the resulting equations are biased. The following statistical procedures would have been better than normalization: (1) employing a speed breakpoint of 16 mph, which is within the data domain of both the low and medium SCFs; (2) employing a weighted least-squares regression; or (3) employing a different functional form.

TABLE 6-8 MOBILE5m-predicted (50th percentile) running exhaust CO and HC emissions rates for facility types and level of service combinations examined (standard deviation of average speed = 0)

	Percentile		
	2.5%	50%	97.5%
Uncongested Freeway			
Mean: 55.0; Std. Dev.: 0.000			
Speed		55.00	
CO		11.06	
HC		0.83	
Congested Freeway			
Mean: 16.0; Std. Dev.: 0.000			
Speed	16.00	16.00	16.00
CO	18.84	24.61	71.87
HC	1.81	2.05	3.35
Uncongested Arterial			
Mean: 30.0; Std. Dev.: 0.000			
Speed	30.00	30.00	30.00
CO	13.12	16.37	25.55
HC	0.97	1.23	1.90
Congested Arterial			
Mean: 8.0; Std. Dev.: 0.000			
Speed	8.00	8.00	8.00
CO	23.66	40.37	340.70
HC	2.65	3.94	12.31

age of all emission rates predicted from individual average vehicle speeds. This holds true for any given functional class and LOS.

The MOBILE5m model can run MOBILE5a for any average speed (between 2.5 and 48 mph) and standard deviation of that average speed. However, the variability associated with the average speed selected for input is a function of the analysis for which MOBILE5m outputs are to be used. If the model is being run to obtain an emission rate for input to a local project impact assessment (e.g., as an input to the CALINE4 line source dispersion model), the average speed of the roadway is a function of the average speeds of the individual vehicle trajectories across this roadway.[4] If the model is being run to obtain an emission rate for regional analysis, where all vehicle activity on each roadway classification under a given LOS is to be assigned a single emission rate, the standard deviation of the average of the averages probably would be employed. However, the standard error associated with an average of averages undoubtedly will be much smaller than the actual variability across all of these roadways and probably will underestimate the confidence bounds associated with the emission rate outputs.

TABLE 6-9 MOBILE5m-predicted (50th percentile) running exhaust CO and HC emissions rates for facility types and level of service combinations examined (standard deviation of average speed as indicated)

	Percentile		
	2.5%	50%	97.5%
Uncongested Freeway			
Mean: 55.0; Std. Dev.: 0.000			
Speed	53.96	55.03	56.08
CO	11.06[1]	11.06	12.89
HC	0.83[1]	0.83	0.88
Congested Freeway			
Mean: 16.0; Std. Dev.: 0.000			
Speed	12.97	16.09	19.13
CO	18.84	24.87	81.74
HC	1.68	2.06	3.88
Uncongested Arterial			
Mean: 30.0; Std. Dev.: 0.000			
Speed	29.57	30.01	30.44
CO	13.16	16.38	25.49
HC	0.98	1.23	1.89
Congested Arterial			
Mean: 8.0; Std. Dev.: 0.000			
Speed	7.24	8.02	8.78
CO	23.61	40.74	341.00
HC	2.64	3.98	12.84

[1] MOBILE5a employs the same CO and HC SCF values for all speeds in the range of 48-55 mph and all speeds in this range result in the same emissions prediction, hence, the 2.5% values equal the 50% values.

Uncongested Freeway	Std.Dev. = 0.55
Congested Freeway	Std.Dev. = 1.60
Uncongested Arterial	Std.Dev. = 0.225
Congested Arterial	Std.Dev. = 0.40

POLICY IMPLICATIONS OF ANALYTICAL RESULTS

Previous studies examined the SCFs in the California EMFAC model (Guensler, 1993; Guensler and Sperling, 1994) in detail and outlined the precautions that should be taken in interpreting modeled changes in emission rates associated with implementation of strategies designed to increase or decrease average vehicle speeds. Although the MOBILE5m analysis for this project employed different SCFs (different technology groups and model functional forms), did not examine NO_x, and did not examine specific changes in emission rates for TCMs, the same general conclusions are likely to be supported by further analysis with MOBILE5m. For example,

> Increasing average vehicle speeds from low speeds (0 to 30 mph) to moderate speeds (between 30 and 45 mph) should provide carbon monoxide benefits for older vehicles, and hydrocarbon emission benefits for all vehicles. However, the carbon monoxide benefits for modern fuel-injected vehicles associated with these speed changes are highly uncertain (Guensler and Sperling, 1994).

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[4] Because the SCFs were derived from driving cycles, it has been recommended elsewhere that average speeds resulting over as long a stretch of travel as possible be used in obtaining emission rates for input to local project impact assessments (Guensler et al., 1994).

The application of SCFs and average speeds to the analysis of emissions along corridors will yield highly uncertain results.

Probably the most important policy implication associated with this analysis is that MOBILE5a outputs should be treated as a planning tool. That is, the emission results from the model should be used as a regional planning tool to assess changes in regional emissions associated with changes in overall travel demand and implementation of regional emission control strategies (e.g., reformulated fuels and I/M) and vehicle emission control technologies (e.g., effects of new certification standards). Emission budgets are useful tools for determining relative regional emissions burdens associated with mobile sources and for planning attainment strategies. However, the actual numerical accuracy of the model outputs should be viewed with caution. Given the uncertainty associated with the average speed relationships, emission control strategies affecting average vehicle speeds are not likely to be adequately modeled using MOBILE5a alone.

Simply because the numerical outputs associated with average speed changes are highly uncertain does not mean that TCMs and TDM designed to minimize congestion are ineffective strategies. It simply means that the existing model cannot evaluate the effects of these strategies to a desired degree of certainty. Indeed, there is mounting evidence that traffic flow-smoothing (reducing low-speed congestion and hard accelerations) can provide significant emissions benefits. Flow-smoothing reduces the frequency of vehicle enrichment (a condition that for many vehicles can lead to tremendous instantaneous increases in grams per second emission rates). CO emission rates (grams per second) under enrichment conditions can soar as high as 2,500 times the emission rate noted for stoichiometric conditions (Kelly and Groblicki, 1993). "Although most vehicles spend less than 2 percent of their total driving time in severe enrichment, this can account for up to 40 percent of the total CO emissions" (LeBlanc et al., 1994). The benefits of flow-smoothing are not well represented in the model through the use of average SCFs; nevertheless, benefits exist in terms of both CO and HC.

Because the noted effect of the standard deviation of input average speeds on output confidence intervals was so small compared with the inherent uncertainty associated with the average speed functions integrated into the MOBILE5a model, it may not be cost-effective to spend significant resources to improve input average speed estimates. Furthermore, claims of improved accuracy of modeled outputs associated with small improvements in average speed estimates should be viewed with some reservation.

CONCLUSIONS

Confidence interval analysis is too often ignored by model developers and almost always ignored by users. Without knowledge of the PDF for each algorithm, an analyst cannot conceptualize the degree of uncertainty associated with using the model algorithm.

Uncertainty associated with the use of existing emission model algorithms can be quantified by revisiting the data used to derive each of the algorithms in the model. Collection of new data is not required in order to assess the uncertainty of model outputs for vehicle emission rates (assuming that a representative sample of vehicles has been collected). However, emission testing data used to develop each numerical algorithm in the models need to be unarchived for analysis. This chapter only examined CO and HC SCFs for low and medium average operating speeds. Follow-up uncertainty analyses are proposed in Appendix D.

Once quantified, uncertainties can be incorporated into policy analyses. Without detailed re-analysis of the data used to develop the algorithms in existing emission rate models, practitioners cannot accurately identify the individual model components that contribute the greatest uncertainty to emissions estimates.

The lack of provision of confidence intervals around average values within the model and predicted model outputs causes an accountability problem in the policy arena. Faced with two alternatives to achieve the same emissions reduction, an informed decision maker needs to know the confidence interval around that predicted value. From a policy perspective, there is a distinct difference between two control strategies designed to reduce emissions by 10 tons per day, when the predicted emission reduction range of one strategy lies somewhere between 5 and 19 tons per day and the predicted emission reduction range of the other lies somewhere between 9 and 11 tons per day. Although both strategies are estimated to achieve the same mean emission reduction, the first strategy carries a higher risk, because the risk of a large emission reduction shortfall with respect to obtaining a desired emission reduction is higher for the case with a wider confidence interval. The failure to achieve predicted emission reductions usually results in the adoption of supplemental strategies with a higher marginal control cost. Therefore, the risks associated with each alternative should be considered. Hence, given that pollution control resources are limited and that cost and effectiveness of strategies are variable, decision makers need uncertainty information if they are to undertake a reasoned return on investment analyses. Worse yet, the uncertainty bounds around some estimated emission relationships are so wide that analysts cannot rule out (with 95 percent certainty) the possibility that some emission reduction policies will actually produce a net emission increase.

Although Monte Carlo uncertainty analysis does not reduce uncertainty in models, the analyses reduce uncertainty in the application of these models. That is, emission estimates based on current models would be used with the level of confidence appropriate to their accuracy, making transportation policies reflective of the current level of uncertainty. Furthermore, such approaches are likely to reduce the overall cost of attaining the ambient air quality standards.

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CHAPTER 7

AGGREGATION ANALYSIS

INTRODUCTION

The interaction of transportation-planning models, air quality emissions models, and the various inputs and assumptions that each requires is complex. This interaction can only be determined by undertaking a full-scale case study. For such an analysis, assumptions relating to those elements of the modeling system that are outside the transportation-planning models themselves are held constant, so that the analysis can identify specifically those aspects of the interaction affected by the implementation of transportation-planning procedures.

Aims

The aims of this chapter are to investigate the following aspects of transportation-planning models and their effects on emissions estimation:

- Changing the level of geographic aggregation,
- Changing the level of time-of-day aggregation,
- Changing assumptions about the day of the week and season, and
- Post-processing highway network speeds.

Current Practice

In current practice, ways in which each of these aspects of modeling is conducted differ, ranging from "standard practice" to "best practice." As defined here, standard practice is what is used in most small- and medium-sized MPOs as well as some of the largest ones, while best practice would be used at a handful of the larger MPOs only. The current modeling process used by the MPO selected for the case study for this research is standard practice. For this research, advanced procedures representing best practice were added systematically to the currently used procedure as described later.

The Case Study MPO

The MPO selected for the case study was the Capital Region Planning Commission in Louisiana, which is the MPO for the Baton Rouge metropolitan area. This selection was based principally on the availability of the data and models and familiarity of the research team with the planning process being used in Baton Rouge.

Description of the Region

The Baton Rouge metropolitan area has a population of about 500,000 (1990). The MPO covers six parishes[1] in southeastern Louisiana, namely East Baton Rouge, West Baton Rouge, Ascension, Iberville, Point Coupee, and Livingston. The urbanized area, which is also where the transportation-planning models are applied, consists of most of East Baton Rouge Parish and portions of Livingston, Ascension, and West Baton Rouge parishes. Approximately 480,000 persons live within the urbanized area. Figure 7-1 shows the location of these parishes in the state and highlights East Baton Rouge Parish, where most of the urban population lives.

The urbanized area is divided by two rivers—on the west side by the Mississippi River and on the east side by the Amite River. Both rivers are barriers to movement, with the Mississippi River providing the greater barrier. Only two bridges cross the Mississippi within the metropolitan area, while the river runs for 12 miles through the urbanized area. The area is served by three interstate highways—Interstate 10, which crosses from the west boundary of the region to the east and is part of the interstate that connects Los Angeles, CA, to Jacksonville, FL; Interstate 110, which provides urban connections from near the Interstate 10 Mississippi River Bridge to just north of the Metropolitan Airport and provides access to downtown Baton Rouge; and Interstate 12, which begins at Interstate 10 on the east side of Baton Rouge and provides a bypass route for Interstate 10 traffic around the New Orleans metropolitan area to the east of Baton Rouge. The metropolitan area is served by a small bus system that operates a few bus routes within East Baton Rouge Parish only and provides contract service to the Louisiana State University campus. Buses in Baton Rouge carry less than 0.5 percent of total daily trips.

Baton Rouge, as the state capital, provides government employment in the downtown and several outlying areas. The

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[1] Louisiana is divided into parishes, which are the equivalent of counties in the remainder of the United States.

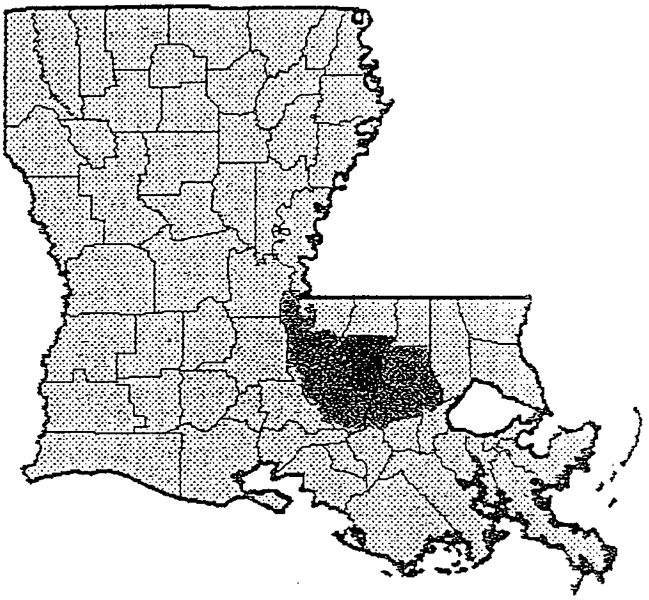

Figure 7-1. State of Lousiana showing parishes in Baton Rouge MSA/MPO.

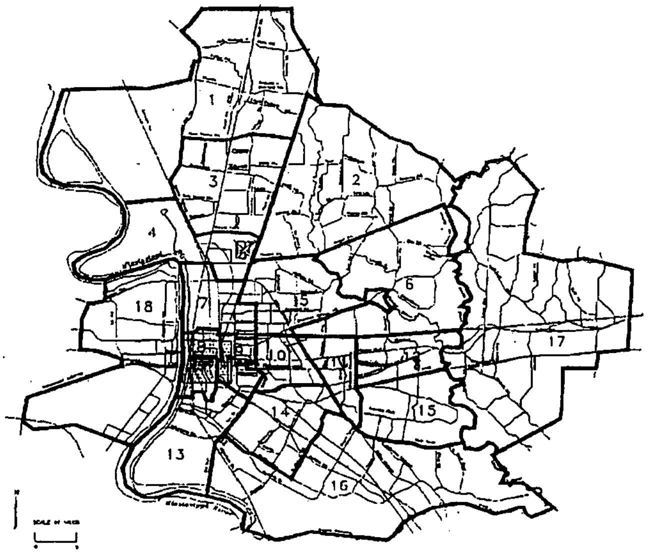

Figure 7-2. Planning area of Baton Rouge, showing district boundaries.

petrochemical industry, located primarily along both banks of the Mississippi River from north of the metropolitan area through to the southern boundary of the area, is the second largest employer. Two local universities—Southern University in the northwest section of the metropolitan area, which is the largest historically black college or university in Louisiana, and Louisiana State University in the southwest section of the metropolitan area, which is the flagship university of the state university system in Louisiana—constitute the third largest source of employment. Residential areas are dispersed throughout the metropolitan area, with major growth occurring to the southeast. The area is primarily low density, with a relatively small central business district (CBD). The area also has an incomplete arterial system, which results in several segments of heavily congested roadways at the height of the morning and evening peaks. Figure 7-2 shows the planning area.

Air Quality Status of the Area

Baton Rouge is classified as an ozone nonattainment area, with a level of Serious nonattainment under CAAA classifications. The nonattainment area comprises the six parishes of the MSA. The area fails to meet the NAAQS primarily because of

- High summer temperatures;
- Stagnant summer air;
- Sufficient sunlight, particularly in the mornings; and
- Industrial and natural sources of ozone precursors (petrochemical industries, congested traffic, and a heavy foliage cover).

During the past 4 years, there have been debates about whether the region is NO_x limited or VOC limited. Recently, it was defined as VOC limited, although this may change. Effort has been directed toward reducing emissions from automobiles. The region has developed a local proposal for I/M (on the basis of decentralized testing) and has implemented vapor recovery at high-volume refueling stations.

Transportation Planning in the Area

The Baton Rouge area undertakes metropolitan planning for an area substantially smaller than the six-parish MPO and nonattainment region. The metropolitan planning area is divided into 364 internal TAZs and 23 external zones, the latter being represented by external-cordon stations. The region, which last conducted a household travel survey in the early 1960s, has no current travel data with which to construct local travel-forecasting models.

From 1989 to 1991, new models were put in place for the area by borrowing models from elsewhere and adjusting them to replicate local traffic counts on major highways. The borrowed models consist of the following:

- Trip production models for home-based work, home-based nonwork, and non-home-based vehicle trips. These are constructed as cross-classification models using household size as the only variable.

  Trip attraction models for home-based work, home-based nonwork, and non-home-based vehicle trips. These are constructed as regression equations relating trips to numbers of occupied dwelling units, school attendance, retail employment, and other employment. Addi-

tional procedures are used to estimate commercial vehicle and internal-external trips that are applied as part of the trip attraction procedure and to constrain not-home-based attractions to not-home-based total productions.
- Trip distribution models for the three vehicle-trip purposes (home-based work, home-based nonwork, not-home-based). These use a gravity model with discrete friction factors, river-crossing penalties for the two rivers, and with some district-to-district K factors. The trip-distribution process includes balancing total attractions to equal total productions for the home-based work and home-based nonwork purposes.

The modeling procedure starts with vehicle trips, so that no conversion is undertaken before assignment to change person trips to vehicle trips, and there is an implicit assumption of vehicle occupancy embedded in the trip rates. Also, there is no mode-choice model, primarily because transit carries less than 0.5 percent of person trips in the region. No explicit adjustment is made to reduce the trips in the trip table for transit use, because it is being assumed that the factors applied throughout the borrowed models that result in acceptable replication of traffic counts have also adjusted for transit ridership. After steps to convert the production-attraction trip tables from trip distribution into origin-destination tables, and the addition of the commercial vehicle and external-internal trips, a conventional capacity-restrained equilibrium network assignment is performed. The assignment is performed with the total trip table and does not involve the estimation of trips for different periods in the day. The process is shown in Figure 7-3.

THE EXPERIMENTAL DESIGN

The experimental design consisted of a building-block process in which a series of experiments would be conducted—each of which would build on the preceding one. To initiate the process, the model system was run for 1990, the year used for producing the SIP inventory, to ensure that the procedures used were identical to those used by the MPO and the state DOT. This, used as a validation step in the process, attempted to replicate precisely the method employed for the original SIP inventory procedure.

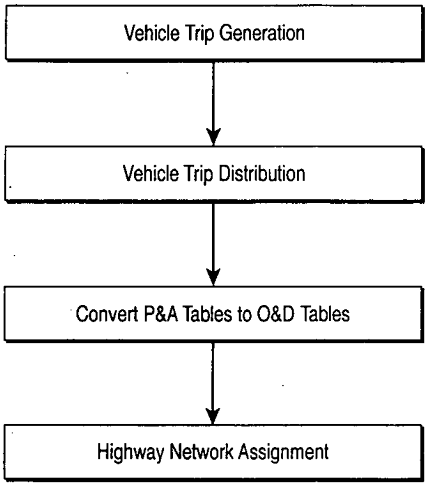

Figure 7-3. The case study planning process.

In the subsequent steps of the procedure, a series of applications of the transportation models was designed in which each step represented greater sophistication and disaggregation in the planning process. Five separate disaggregation scenarios were selected for investigation in this process. These were

- Spatial disaggregation of the links of the network for the purposes of estimating VMT and speeds;
- Separation of the 24-hr period into morning peak, midday, evening peak, and night, but applying factors immediately before highway network assignment;
- An improvement on the preceding step, in which the factors are applied immediately after trip generation, and separate trip distributions are performed for the periods for each trip purpose, using appropriate network travel times;
- Applying seasonal and day-of-week adjustments to the trips estimated from trip generation to reflect summer travel on the highest volume weekday; and
- Post-processing speeds at the end of assignment, before estimating speeds and VMT for the emissions modeling.

The sequence of these tests and the manner in which they build on each other is illustrated by Table 7-1. In Table 7-1, Runs 2 through 6 all use spatial disaggregation, Runs 3 through 6 all use one or the other of two diurnal factoring procedures, while Runs 5 and 6 both use seasonal and daily adjustments.

Run 1—The Base Case

This run involved applying the same methodology as used in the 1990 SIP inventory, but to a 1994 base year. This was done to provide the baseline with which all subsequent runs were to be compared. The process involved

- Running the transportation-planning models for Baton Rouge for 1994, using the exact same procedures as were used for the SIP inventory preparation.
- Preparing an input file for MOBILE5a, using summary outputs from the modeling process, with total VMT and an average speed for each combination of facility type and area type;
- Using average temperatures for fall and spring as input to MOBILE5a and setting all other input parameters to values used in prior estimates for Baton Rouge, including fleet data, anti-tampering, and vapor recovery (the parameter values are defined in Table 7-2).

TABLE 7-1 Testing procedure

	Test Number					
Procedure	1	2	3	4	5	6
Base Case	Yes	-	-	-	-	-
Spatial Disaggregation	-	Yes	Yes	Yes	Yes	Yes
Diurnal Factoring (Pre-Assignment)	-	-	Yes	No	No	No
Diurnal Factoring (Post-Generation)	-	-	-	Yes	Yes	Yes
Seasonal and Daily Factoring	-	-	-	-	Yes	Yes
Post-processed Speeds	-	-	-	-	-	Yes

This run provided estimates for 1994 that would be the equivalent of how emissions estimates have been prepared in the past for Baton Rouge and consistent with the way in which many urbanized areas would use transportation-planning models to arrive at estimates of emissions.

Run 2—Spatial Disaggregation

In this run, an experimental program developed for the Florida DOT was used. This program, named EMIS, provided an interface between standard TRANPLAN operation and MOBILE5a and estimated the emissions factors for each link in the highway network, on the basis of the speed on the link. Emission factors were calculated for 3 mph increments of speed, and the appropriate emissions value was selected for each link to estimate the emission factor. This factor was then applied to the VMT on the link to estimate the total emissions from the link. These emissions were then summed for each facility type and area type. Optionally, the link data could be summed by grid square or by any other geography that could be input to the process.

Comparison of this run with Run 1 provided information on the loss of accuracy that occurs as a result of aggregating within facility type and area type and using a single speed for each combination of facility type and area type to estimate emissions. In Run 2, no other changes were made to any of the steps in the process, and all parameters for MOBILE 5a remained unchanged from Run 1.

Run 3—Diurnal Factoring Before Traffic Assignment

In Runs 3 and 4, alternative approaches were taken to estimation by time period. In Run 3, the "conventional" approach was taken, in which diurnal factors are applied immediately before traffic assignment, during the process in which trip tables for different trip purposes are converted from production-attraction tables to origin-destination tables, and the trip purposes are added together. A set of diurnal factors was developed for use in this study. The factors were applied before assignment to produce four trip tables for assignment, representing 1 hr from each of the a.m. peak period (7 a.m. to 9 a.m.), the midday period (9 a.m. to 4 p.m.), the p.m. peak period (4 p.m. to 6 p.m.), and the night period (6 p.m. to 7 a.m.). The same trip tables produced from Run 1 and used in Run 2 were used for this step. The highway network data were modified to provide 1-hr capacities on all links.

One additional change was made to the inputs to MOBILE5a in this step. This was to use different average fall and spring temperatures for each time period, on the basis of meteorological data for Baton Rouge. The EMIS program was used to develop the emissions estimates, thus retaining the spatial disaggregation of Run 2.

TABLE 7-2 Parameters used as input to MOBILE5a for all runs

Parameter	Source/Value
Vehicle Type and Age	Department of Motor Vehicles data for Louisiana
Anti-Tampering Program	In operation
Fuel Volatility	Class C
In-Use RVP	7.8 psi
Region	Low altitude
Calendar Year	1994
Operating Modes	Default Values
Month of Analysis	March
Fraction of VMT by Vehicle Type	Louisiana Department of Transportation and Development data

Run 4—Diurnal Factoring After Trip Generation

In Run 4, the diurnal factoring was moved back in the transportation-planning process to follow the trip generation models. The purpose of this step was to separate the estimated productions and attractions into the four time periods and then perform trip distribution with different input data from the networks according to time period. Thus, trip distribution in the a.m. peak was performed using estimated congested travel times in the network from the a.m. peak (using the output estimates of speeds from Run 3), while the midday and night each used uncongested travel times, and the p.m. peak used congested travel times estimated from the p.m. peak.

Other aspects of Run 4 were identical to Run 3, including the use of the different temperature inputs and hourly capacities throughout the network. The EMIS program was used in Run 4 as well as in Run 3 to maintain spatial disaggregation in the estimation of the emissions.

Run 5—Seasonal and Day-of-Week Adjustments

In Run 5, adjustments were made to reflect differences between the times for which transportation-planning estimates are prepared and the times for which emissions estimates are typically required. In standard transportation-planning practice, data are collected in the fall and/or spring and are designed to cover all weekdays at the same rate, so that the resulting data represent an average weekday in either the fall or spring. In ozone nonattainment areas, the highest exceedance days are usually a specific day of the week in the summer, while CO exceedances occur on a specific day in the winter. In this run, factors were developed and applied to each trip purpose to approximate the highest weekday volume in the summer. Factors for this purpose were developed from NPTS data for 1990, using national averages.

A second change was made in this run—this is to use the average summer temperatures by time period for estimation of the emissions, replacing the average fall and spring temperatures used in the preceding runs. Other aspects of the estimation process were the same as Run 4.

Run 6—Post-Processed Speeds

In Run 6, a further change was made to the results of Run 5. Instead of using the speeds produced from the TRANPLAN traffic assignment step as the speeds for estimating emissions, an additional analysis was done to recalculate the speeds before running EMIS, in which a different speed-to-volume relationship (shown in prior work to give more accurate estimates of travel speeds) was used. The rationale for this step was that the standard BPR Capacity Restraint Function has been found to mis-estimate speeds by as much as ±40 percent on some facility types, although it is the proven method by which to replicate link volumes with reasonable accuracy.

Run 6, therefore, used the results of Run 5 for the summer highest-volume weekday and post-processed the speed data from the highway network after the assignment and before running the EMIS program to compute emission factors on each link. In other respects, Run 6 was the same as Run 5.

Summary of Runs Through TRANPLAN and Emissions Estimation

Table 7-3 summarizes the steps used in each of the runs and indicates specifically the run number for each TRANPLAN step that corresponds to what is used in the estimation process. The interpretation of this table follows along the lines that, for example, trip generation is run only once for Run 1, and the results from that run are used in all subsequent runs. The network building for Runs 1 and 2 is done once in Run 1, and the same network is used in Run 2. A dif-

TABLE 7-3 TRANPLAN and emissions procedures for each run of the aggregation analysis

	Run Number					
Procedure	1	2	3	4	5	6
Trip Generation	1	1	1	1	1	1
Network Building	1	1	3	4	4	4
Diurnal Factoring of Ps and As	No	No	No	4	4	4
Seasonal and Daily Factors	No	No	No	No	5	5
Trip Distribution	1	1	3	4	5	5
Diurnal Factoring of Origins and Destinations	No	No	3	No	No	No
Highway Assignment	1	1	3	4	5	5
Post-Processing of Speeds	No	No	No	No	No	6
Temperatures	1	1	3	3	5	5
EMIS for Emissions	No	2	3	4	5	6

ferent network is built for Run 3, and still a different one for Run 4. The Run 4 network is used in Runs 5 and 6.

DESCRIPTION OF RESULTS OF THE AGGREGATION ANALYSIS

This section describes the results obtained from the different runs, as well as estimates of input values used for such elements as the diurnal factoring and the seasonal and daily factoring. The initial step was to run a validation test in which estimates were made for 1990 in a manner that paralleled the method used by the MPO and state DOT. The results of this test were to validate that the procedure used was consistent with the methods employed by the local agencies.

In the following sections, a description of results is provided for each of the six runs. The six runs are compared and conclusions are drawn concerning the effects of the various disaggregation steps. In each section, average speeds are reported for the purpose of comparing the runs. The average speed is determined by dividing the VMT by the VHT. This figure is used for emissions estimation only in Run 1. In the other runs, the average speed is reported only as a comparison statistic; emissions are calculated using an average speed on each link within each facility class. For Runs 3 through 6, computations of the daily and 24-hr emissions are all performed using grams and converting to U.S. tons after summation, although the individual tables report hourly emissions by U.S. ton.

Run 1—1994 Base Case

In the base case, the transportation-planning models were run as currently set up for the region, and outputs were obtained that provided estimates of the VMT and speeds by facility type and area type for the region. The speeds, together with the input data specified in Table 7-2 and using the average of spring and fall temperatures (averaged for high, low, and ambient from the months of February, March, April, September, October, and November) were input to MOBILE5a and the resulting emissions factors were multiplied by VMT to produce the estimated total emissions for VOCs, CO, and NO_x, as shown in Table 7-4.

In this and all subsequent tables, facility type 1 is freeway, facility type 2 is primary arterial, facility type 3 is secondary arterial, facility type 4 is collector/distributor, and facility type 5 is centroid connector. Only two area types were defined—urban and rural. The total daily emissions are provided in both kilograms and tons in the last two lines of the table.

Run 2—Spatial Disaggregation

In this run, EMIS was used in conjunction with TRANPLAN, run identically to Run 1, so that the only difference between Runs 1 and 2 is the estimation of emission factors on a link-by-link basis. The results, showing the VMT, VHT, average speeds, and the three criterion pollutants, are shown in Table 7-5. The average speeds are computed by dividing the VMT by the VHT. In Run 2, the average speeds are not used to compute the emissions, and the values of average speed are identical with Run 1, because VMT and VHT values are sums for all links in both runs. Overall, Run 2 produces higher estimates of each pollutant, with the increases being 3.46 percent for VOCs (15.59 tons in Run 2 versus 15.07 tons in Run 1), 7.8 percent for CO (156.02 tons versus 144.73 tons), and 4.28 percent for NO_x (32.10 tons versus 30.86 tons). The reasons for the increases can be seen by comparing the emissions by facility type and area type, as shown in Table 7-6. Table 7-6 shows that the link-by-link emissions estimation predicts increased VOC emissions estimates for urban facilities and decreased emissions estimates in rural areas. All nonfreeway rural facilities also show minor increases in VOCs. These changes are consistent with a skewed distribution of speeds on the links, which is gener-

TABLE 7-4 Results of Run 1: 24-hour emissions calculation using average speeds by functional class and area type

Facility Type	Area Type	VMT	VHT	Speed (mph)	Emissions (kilograms)		
					VOC	CO	NOx
1	Urban	2,165,030	40,991	52.82	2,576.4	24,334.9	7,339.5
1	Rural	408,360	6,681	61.12	584.0	8,608.2	1,764.1
2	Urban	2,357,880	60,611	38.90	3,253.9	29,827.2	6,531.3
2	Rural	112,960	2,099	53.82	133.3	1,274.2	395.4
3	Urban	1,947,885	53,769	36.23	2,824.4	25,984.8	5,337.2
3	Rural	223,539	4,801	46.56	275.0	2,528.2	648.3
4	Urban	577,919	16,622	34.77	861.1	7,952.2	1,577.7
4	Rural	744,843	16,281	45.75	923.6	8,498.7	2,145.1
5	Urban	803,340	53,556	15.00	2,249.4	22,405.2	2,281.5
Total		9,304,942	252,956	36.78	13,681.0	131,413.5	28,020.1
Tons					15.07	144.73	30.86

TABLE 7-5 Results of Run 2: 24-hour emissions calculation using link speeds by functional class and area type

Facility Type	Area Type	VMT	VHT	Speed (mph)	Emissions (kilograms) VOC	CO	NOx
1	Urban	2,165,030	40,990	52.82	2,805.1	31,226.1	7,810.2
1	Rural	408,359	6,681	61.12	529.5	7,781.9	1,590.1
2	Urban	2,357,882	60,611	38.90	3,349.4	31,339.9	6,907.9
2	Rural	112,960	2,099	53.82	138.6	1,380.5	403.2
3	Urban	1,947,883	53,769	36.23	2,894.6	26,968.4	5,548.8
3	Rural	223,538	4,802	46.55	283.2	2,646.9	679.9
4	Urban	577,919	16,622	34.77	882.7	8,219.2	1,626.5
4	Rural	744,844	16,281	45.75	965.4	9,161.5	2,339.3
5	Urban	803,340	53,556	15.00	2,305.6	22,943.4	2,313.6
Total		9,341,755	255,411	36.58	14,154.1	141,668.0	29,219.6
Tons					15.59	156.02	32.18

ally to be expected. The effects of the link-by-link estimation are almost identical for CO as for VOCs. Surprisingly, the same pattern of results also occurs for NO_x, which is not expected, except insofar as links tend to have speeds that are distant from the mean speeds, with both higher and lower values of speed tending to be present on the individual links. In addition, on freeways, higher speeds on individual links may give rise to higher emissions of both VOCs and NO_x as a result of speeds in the range where VOCs begin to increase again with increasing speed.

Run 3—Diurnal Factoring Before Assignment

In this run, diurnal factors were applied before assignment in order to arrive at separate peak and midday assignments with appropriate speeds. An initial attempt to develop diurnal factors from local data proved to be inappropriate. The only local data available for estimation of diurnal factors were data from an external cordon survey conducted in 1989 for the purposes of updating and improving a set of borrowed travel forecasting models. The problem with the external cordon data was that the data contained far fewer non-home-based trips than would be expected in urban travel data and most of the non-home-based trips were in the peak periods. This is unlike almost any other distribution of trips by time of day.

Several sources were reviewed for data on diurnal distributions; most provided distributions of person trips, whereas vehicle trips were required for the Baton Rouge models, which are entirely vehicle-trip models. After checking several sources of person-trip factors for consistency, the research team found that the diurnal distributions of person trips from Sacramento and Los Angeles were similar and did not appear to differ substantially from NPTS data of 1990 (although the trip purposes in NPTS are not readily matched to urban transportation-planning purposes). Table 7-7 shows the diurnal factors for person trips from Sacramento and Los Angeles. Los Angeles data are from both the Southern California Association of Governments (SCAG) and CALTRANS. The SCAG data use a morning peak from 7 a.m. to 9 a.m. and an evening peak from 3 p.m. to 6 p.m. The CALTRANS and Sacramento data were derived using a morning peak from 7 a.m. to 9 a.m. and an evening peak from 4 p.m. to 6 p.m. The diurnal distribution of work trips from the Baton Rouge data for vehicle trips was consistent with

TABLE 7-6 Comparison of emissions by facility type and area type—Runs 1 and 2

Facility Type	Area Type	Emissions (kilograms) VOC Run 1	VOC Run 2	CO Run 1	CO Run 2	NOx Run 1	NOx Run 2
1	Urban	2,576.4	2,805.1	24,334.9	31,226.1	7,339.5	7,810.2
1	Rural	584.0	529.5	8,608.2	7,781.9	1,764.1	1,590.1
2	Urban	3,253.9	3,349.4	29,827.2	31,339.9	6,531.3	6,907.9
2	Rural	133.3	138.6	1,274.2	1,380.5	395.4	403.2
3	Urban	2,824.4	2,894.6	25,984.8	26,968.4	5,337.2	5,548.8
3	Rural	275.0	283.2	2,528.2	2,646.9	648.3	679.9
4	Urban	861.1	882.7	7,952.2	8,219.2	1,577.7	1,626.5
4	Rural	923.6	965.4	8,498.7	9,161.5	2,145.1	2,339.3
5	Urban	2,249.4	2,305.6	22,405.2	22,943.4	2,281.5	2,313.6
Total		13,681.0	14,154.1	131,413.5	141,668.0	28,020.1	29,219.6

TABLE 7-7 **Comparison of hourly diurnal factors for person trips from California sources**

Source	Purpose	A.M. Peak	Midday	P.M. Peak	Night	Total
SCAG	Home-Based Work	11.92%	1.90%	11.81%	1.45%	100.00%
	Home-Based Nonwork	2.73%	5.59%	8.06%	2.85%	100.00%
	Not-Home-Based	2.92%	7.64%	8.56%	1.64%	99.98%
CALTRANS	Home-Based Work	13.19%	2.57%	14.41%	2.06%	99.99%
	Home-Based Nonwork	3.61%	5.92%	9.07%	2.70%	101.93%
	Not-Home-Based	3.75%	7.87%	7.81%	1.61%	99.14%
Sacramento	Home-Based Work	11.05%	3.13%	11.35%	2.56%	100.00%
	Home-Based Nonwork	5.55%	6.34%	7.35%	2.29%	100.00%
	Not-Home-Based	2.05%	7.86%	9.20%	1.73%	100.00%

the data in Table 7-7, with an hourly figure of 12.45 percent, which lies between the Sacramento and CALTRANS person-trip figures.

On the basis of these various comparisons, the only available vehicle-trip distribution, from Los Angeles, was used. The factors are shown in Table 7-8. In this case, the comparison to the Baton Rouge figures from the external cordon show 11.15 percent in the p.m.-to-a.m. (P-A) direction and 1.3 percent in the a.m-to-p.m (A-P) direction.

In common with all of the diurnal distributions found, these figures show imbalances between the two directions. The Sacramento data, by direction, had 49.1 percent P-A and 50.9 percent A-P for the home-based work trips, and 51.2 percent and 48.8 percent for the P-A and A-P, respectively, for the home-based nonwork trips. The imbalances in Table 7-8 are more marked and probably should be reflected in differences in the not-home-based trips, so that total trips would balance. However, no attempt to do this was made in this exercise. (Differences in occupancy will also contribute to the imbalances on vehicle trips, where people may ride with different numbers of other people, depending on the direction of travel.)

The next step required for Run 3 and subsequent runs was to change the capacities coded on the network. For the purposes of a 24-hr assignment, capacities coded on the Baton Rouge network are for multiple hours. Specifically, a multiplier-based on K-factor is used so that, while volumes will be assigned for the entire 24-hr period, V/C ratios, used for developing capacity change recommendations, are designed to replicate peak hour V/C ratios. This common procedure has been used for many years and has produced useful volume data for design purposes. However, in the process of returning capacity measures to 1-hr capacities, as required for loading hourly trip totals, it was realized that this standard practice by most MPOs results in computation of emissions using peak-hour speeds for 24-hr traffic. The result that would be anticipated from this is that VOCs would be significantly overestimated (as a result of using lower speeds than are correct) and NO_x would be significantly underestimated for the same reason.

Initially, it was assumed, as is standard, that the capacities coded on the Baton Rouge network were 10 times the hourly capacity. However, although this resulted in reasonable capacity estimates, it did not result in V/C ratios for the a.m. peak that were consistent with those obtained from the original runs. Given that the coded capacities were intended to produce good estimates of actual peak V/C ratios, the research team decided to adjust the factored capacities to replicate the original peak ratios. One reason for a mismatch, using the diurnal factors from Table 7-8 and capacities divided by 10 would be that the actual Baton Rouge percentages of trips in the peak period are different from the cordon data and the California data. Also, the vehicle trip generation models for Baton Rouge may underestimate total home-based work trips. The final conversion made was to multiply

TABLE 7-8 **Selected directional hourly diurnal vehicle-trip factors for Runs 3 and 4**

Purpose	P-A/A-P	A.M. Peak	Midday	P.M. Peak	Night	Total
Home-Based Work	P-A	11.58%	1.13%	1.11%	0.85%	54.99%
	A-P	0.21%	0.88%	10.41%	0.66%	45.02%
Home-Based Nonwork	P-A	2.27%	3.12%	3.09%	1.44%	52.02%
	A-P	0.38%	2.75%	5.04%	1.27%	47.98%
Not-Home-Based	P-A	1.51%	4.07%	4.12%	0.73%	50.00%
	A-P	1.51%	4.07%	4.12%	0.73%	50.00%

TABLE 7-9 Temperature by time period used in Runs 3 and 4

Period	Hours	Min. (°F)	Max. (°F)	Ambient (°F)
A.M. Peak	07:00-09:00	56.8	62.2	58.8
Midday	09:00-16:00	62.2	73.3	71.4
P.M. Peak	16:00-18:00	69.8	73.1	71.9
Night	18:00-07:00	56.8	69.8	60.2

the capacities by 0.7, which then produced reasonably consistent V/C ratios for the a.m. peak period (although the V/C ratios from this calculation generally were lower than those obtained from the 24-hr network, i.e., traffic was less congested than in the 24-hr assignment).

The final change made from Run 2 to Run 3 was that the temperatures were changed for each time period. The average maximum, minimum, and ambient temperatures were computed from Baton Rouge meteorological records for the spring and fall for each of the four time periods. These resulted in the use of the temperatures shown in Table 7-9.

The results of Run 3 are shown in Tables 7-10 through 7-13 for the a.m. peak, midday, p.m. peak, and night. Table 7-14 provides the summation of the hourly estimates by time period to the entire day and provides comparisons with the results of Runs 1 and 2. Table 7-14 shows that the estimates of each of the three criterion pollutants have increased with each step of disaggregation to this point. For VOCs, the increase from Run 1 to Run 2 is 3.5 percent, while the increase from Run 1 to Run 3 is 4.9 percent. For CO, the increase is 7.8 percent from Run 1 to Run 2 and 12.5 percent from Run 1 to Run 3. For NO_x, the increases are 4.3 percent and 5.7 percent for Run 2 and Run 3 over Run 1, respectively. The daytime emissions are 73.7 percent of 24-hr emissions for VOCs, 72.3 percent for CO, and 72.9 percent for NO_x, respectively. The increases in emissions shown in Run 3 are less dramatic than might have been expected, because Runs 1 and 2 are derived using peak-period speeds for all-day traffic.

Run 4—Diurnal Factoring After Trip Generation

Run 4 used the same diurnal factors as Run 3, shown earlier in Table 7-8. The primary changes in this run from Run 3 were that the diurnal factors were applied immediately following trip generation, and trip distribution was run 4 times for each trip purpose, using congested travel times for the a.m. and p.m. peaks and uncongested travel times for the midday and night. The estimates of travel times for the a.m. peak were taken from the assignment step of Run 3 for the a.m. peak and, similarly, those for the p.m. peak were taken from the p.m. assignment of Run 3. The midday and night travel times were the free-flow travel times coded into the original networks. The same temperatures, shown earlier in Table 7-9, were used in Run 4 as in Run 3.

The results of Run 4 are summarized in Table 7-15. Table 7-14 provides the summation of the hourly estimates by time period for the entire day and provides comparisons with the results of Runs 1 and 2.

The differences between Runs 3 and 4 were generally quite small. Run 4 gave slightly higher estimates of two of the three pollutants for the 24-hr period and a slightly lower estimate of one, as a result of estimation of more accurate speeds for each time period and slight differences in the trip distribution for Run 4 as compared with Run 3. VOCs were hardly affected by the joint changes of period speeds and trip distribution, while CO increased marginally, and NO_x decreased marginally. The decrease in NO_x was almost cer-

TABLE 7-10 Results of Run 3: a.m. peak 1-hour emissions calculations using link speeds by functional class and area type

Facility Type	Area Type	VMT	VHT	Speed (mph)	Emissions (kilograms) VOC	CO	NOx
1	Urban	127,032	2,346	54.15	177.07	2,238.29	496.66
1	Rural	22,243	360	61.79	36.20	598.00	105.12
2	Urban	142,386	3,500	40.68	205.83	2,128.58	437.42
2	Rural	6,190	114	54.30	8.00	87.85	23.36
3	Urban	107,946	2,880	37.48	164.07	1,688.20	322.36
3	Rural	12,410	253	49.05	16.22	168.50	42.05
4	Urban	30,722	856	35.89	48.08	495.16	90.67
4	Rural	41,816	907	46.10	56.76	595.23	138.59
5	Urban	42,396	2,826	15.00	128.46	1,404.16	127.19
Total		533,141	14,042	37.97	840.67	9,403.96	1,783.43
Tons					0.93	10.36	1.96

TABLE 7-11 Results of Run 3: midday emissions for 1 hour

Facility Type	Area Type	VMT	VHT	Speed (mph)	Emissions (kilograms) VOC	CO	NOx
1	Urban	126,867	2,329	54.47	165.97	1,923.07	475.32
1	Rural	24,640	400	61.60	36.50	553.64	110.21
2	Urban	143,374	3,542	40.48	196.52	1,817.77	421.08
2	Rural	6,846	127	53.91	8.33	81.57	24.41
3	Urban	114,068	3,039	37.53	163.46	1,498.14	323.72
3	Rural	13,250	272	48.71	16.40	151.87	42.08
4	Urban	32,588	906	35.97	48.02	439.73	91.42
4	Rural	43,974	941	46.73	55.95	523.80	138.92
5	Urban	48,981	3,265	15.00	138.62	1,361.17	140.09
Total		554,588	14,821	37.42	829.75	8,350.75	1,767.24
Tons					0.91	9.2	1.95

tainly a result of lower speeds being used in the peak periods, while the slight increase in CO probably stemmed from the same change. Comparing Runs 3 and 4 for daytime emissions, all three pollutants were estimated in lower quantities by Run 4 than by Run 3. Comparisons by time of day show that Run 4 had slightly lower estimates of VOCs, CO, and NO_x for the morning peak, with lower average speed and lower VMT than Run 3. The speed and VMT effects on NO_x were both in the same direction and reduced this pollutant. For VOCs and CO, the VMT reductions outweighed the increases resulting from lower speeds, leading to net decreases in both of these pollutants. In the midday, VOCs and CO were both higher in Run 4 than in Run 3, while NO_x was unchanged. VMT was higher and speeds were about the same. In the evening peak, VMT was substantially lower in Run 4 and speeds were also substantially lower, resulting in a decrease in all three pollutants, with the speed and VMT changes again reducing NO_x. VMT decreases outweighed the effects of speed decreases to give net decreases in the other two pollutants. In the night, VMT was higher, speeds were, on the average, marginally higher, and the increased VMT caused an increase in all three pollutants.

Run 5—Seasonal and Daily Factoring

In Run 5, factors were applied to change the season of the year to summer and the day of the week to the highest traffic day of the week. These adjustments were applied to convert the previous estimates from spring and fall to summer, and an average weekday to the highest traveled weekday. New temperatures were used as input for this run, reflecting the average of May through August temperatures in Baton Rouge for each of the time periods. These temperatures are shown in Table 7-16.

Comparing Table 7-16 with Table 7-9, which shows the average spring and fall temperatures, it will be noted that the temperatures are almost 20°F higher in the summer than in the spring and fall. These changes in temperature represented the only input change made to the MOBILE5a inputs, other than the speed changes discussed below and the application to the outputs of the revised VMT estimates. Table 7-17 shows the seasonal and daily factors used to adjust (reflecting the productions and attractions from Run 4) to represent an average summer day and the highest weekday of the summer respectively.

The factors shown in Table 7-17 were derived from the NPTS data of 1990 and represent averages across the country. Home-based nonwork and non-home-based trips are not differentiated as such in NPTS reports, so that the factors were developed for all non-work trips as recorded in NPTS.

Table 7-18 shows the results of Run 5 for each time period and the sum for daylight times and the 24-hr period. Estimates were produced in two steps. In the first step, adjustment was made just for the season, with the appropriate temperatures and the reductions in trips generated by the factors shown in the second column of Table 7-17. In the second step, the additional factoring to the peak day of the week (Tuesday) was also applied.

Table 7-18 shows that the effect of using the peak day of the week is much more significant than the seasonal change. There are substantial increases in both trips and VMT by using the peak weekday and there are drops in speed in all time periods, except the night, of about 2 mph. Table 7-19 provides a comparison of the results of Runs 1 through 5, so that the effects can be seen more clearly. In this table, the hourly emissions are shown only for Run 4 and the two versions of Run 5, because comparisons have already been made between Runs 3 and 4, and differences were generally found to be small.

A comparison of hourly emissions of Run 4 with the seasonal adjustment of Run 5 shows that the summer adjustment resulted in a small increase in speeds for all time periods, which was generated by a concomitant decrease in VMT and trips. These had the net effect of reducing the VOCs in the

TABLE 7-12 Results of Run 3: p.m. peak emissions for 1 hour

Facility Type	Area Type	VMT	VHT	Speed (mph)	Emissions (kilograms) VOC	CO	NOx
1	Urban	214,987	4,812	44.68	280.10	2,662.51	673.48
1	Rural	41,163	711	57.89	54.14	671.84	164.75
2	Urban	227,474	7,217	31.52	364.42	3,390.24	640.52
2	Rural	11,222	218	51.48	13.53	126.50	37.85
3	Urban	211,180	7,388	28.58	361.44	3,382.01	589.10
3	Rural	22,896	619	36.99	32.93	301.95	64.84
4	Urban	69,658	2,407	28.94	118.53	1,106.17	193.01
4	Rural	76,225	1,858	41.03	103.11	958.99	229.69
5	Urban	80,611	5,374	15.00	226.52	2,224.07	230.55
Total		955,416	30,604	31.22	1,554.72	14,824.26	2,823.79
Tons					1.71	16.33	3.11

a.m. peak and the night, but resulted in increased VOCs in the midday and the p.m. peak. As a result, total VOCs for either 24 hr or the daylight period showed an increase. CO exhibited decreases in all time periods, with a resulting decrease for the entire day or for 24 hr. NO_x behaved identically to CO, showing a decrease in all time periods.

When adjustments were made to the peak weekday (Tuesday), the results were dramatic, because the reduction for the summer is much smaller than the variation by day of week. Comparing the results of Run 5 with both a seasonal and day-of-week adjustment, with those of Run 5 with the seasonal adjustment only, and with Run 4, respectively it can be seen that peak period trips and VMT increased not only over the seasonal-only version of Run 5, but over Run 4. There was a concomitant reduction in speed, which produced higher VOCs, but lower CO and NO_x than Run 4 (although both were higher than in Run 5 with seasonal-only adjustments). In the midday period, the number of trips was higher than Run 5 with seasonal-only adjustments, but lower than Run 4. VMT and VHT both behaved similarly, so that speed in the midday was slightly higher than in Run 4, but lower than in Run 5 seasonal only. The higher VMT resulted in an increase in VOCs for this period, while CO was identical with Run 4 and higher than in Run 5 with seasonal adjustments only. NO_x behaved similarly to CO, except that it was lower than the Run 4 result. In the p.m. peak, trips were higher than either Run 5 seasonal only, or Run 4, and VMT was substantially higher. Average speed was the lowest of the three test results. Not surprisingly, both VOCs and CO were higher for this run than for either of the other two runs. On the other hand, the reduced speed had more effect on NO_x than the increased VMT, so that the value for this emission was above that for Run 5 with seasonal adjustments only, but just below Run 4. For the night period, trips were higher than in the previous two runs, and so were both VMT and VHT, resulting in a lower average speed than in either of the previous two runs. The result of these changes was that VOCs were higher than Run 5 with seasonal-only adjustments and identical to Run 4; CO was lower than Run 4, but higher than the seasonal-only Run 5; and NO_x behaved the same as CO.

Looking at the 24-hr and daytime totals for the full Run 5, the VOCs were higher than in any other run, including Runs 1 through 3. In fact, the Run 5 result was almost 15 percent higher than Run 1. CO was not as high as Runs 2 through 4

TABLE 7-13 Results of Run 3: nighttime emissions for 1 hour

Facility Type	Area Type	VMT	VHT	Speed (mph)	Emissions (kilograms) VOC	CO	NOx
1	Urban	43,056	762	56.50	52.49	681.02	149.20
1	Rural	8,753	141	62.08	7.12	107.55	20.77
2	Urban	61,123	1,355	45.11	83.54	863.36	193.77
2	Rural	2,516	46	54.70	3.26	35.61	9.49
3	Urban	34,170	847	40.34	49.36	499.05	102.75
3	Rural	4,719	92	51.29	6.22	66.64	16.77
4	Urban	9,062	240	37.76	13.64	137.96	26.83
4	Rural	15,563	326	47.74	20.83	217.26	52.19
5	Urban	16,751	1,117	15.00	50.42	544.42	50.09
Total		195,713	4,926	39.73	286.88	3,152.87	621.86
Tons					0.32	3.47	0.68

TABLE 7-14 Comparison of 24-hour totals for Runs 1–3

Source	Period	Trips	VMT	VHT	VOC (tons)	CO (tons)	NOx (tons)
Run 3	a.m.	77,964	533,141	14,042	0.93	10.36	1.96
Hourly	Midday	90,944	554,588	14,821	0.91	9.2	1.95
	p.m.	144,300	955,416	30,604	1.71	16.33	3.11
	Night	31,446	195,713	4,926	0.32	3.47	0.68
Run 3	a.m+Midday+p.m.	1,081,136	6,859,230	193,039	11.65	117.78	23.79
Total	24-Hour	1,489,934	9,403,499	257,077	15.81	162.89	32.63
Run 1	24-Hour	1,472,723	9,341,755	255,411	15.07	144.73	30.86
Run 2	24-Hour	1,472,723	9,341,755	255,411	15.59	156.02	32.18

and was only a little higher than in Run 1. Similarly, NO_x was higher than the Run 1 result, but not as high as for Runs 2 through 4. For the daytime-only figures in Runs 3 through 5, the same pattern was evident. The comparisons of these results are shown in Figure 7-4. (For the sake of scaling, the CO figures are expressed in units of 10 tons in this figure, while the other two emissions are in tons.) The figure shows that the variations were relatively small over the five different runs, but that the final run, so far, was higher than the initial estimates from Run 1 for all pollutants. Figure 7-4 also shows that the estimates for VOCs rose with each step in the disaggregation analysis, while CO peaked in Run 4 and declined slightly, but rose in the second of the two Run 5 procedures; NO_x peaked at Run 3, then dropped on the next two runs, and rose again on the second of the Run 5 procedures.

Figure 7-5 shows similar results for Runs 3 through 5 for the daytime-only period, represented by the sum of the a.m. peak, midday, and p.m. peak emissions. Again, VOCs increased fairly uniformly as the disaggregation level was increased, while CO and NO_x declined. These results suggest that the daytime production of VOCs may be being significantly underestimated by procedures akin to the initial method used. To illustrate this, given that the a.m. peak, midday, and p.m. peak periods constitute 11 hr as defined in these analyses, prorated figures have been entered into Figure 7-5 for the first two runs. These figures represent 11/24 of the estimates produced by those runs. This shows dramatically the underestimation that will probably result if 24-hr emissions figures are simply prorated to hourly figures throughout the day. In such a method, Runs 1 and 2 would provide substantial underestimates of the emissions for use in regional air-pollution modeling.

A final analysis was performed relating to this run. In this final analysis, an effort was made to determine the amount of effect produced simply by the higher summer temperatures. This was done by re-running Runs 1 and 2 with the summer

TABLE 7-15 Comparison of 24-hour totals for Runs 1, 3, and 4

Source	Period	Trips	VMT	VHT	Avg. Speed	Emissions (Tons) VOC	CO	NOx
Run 3	a.m.	77,964	533,141	14,042	37.97	0.93	10.36	1.96
Hourly	Midday	90,944	554,588	14,821	37.42	0.91	9.20	1.95
	p.m.	144,300	955,416	30,604	31.22	1.71	16.33	3.11
	Night	31,446	195,713	4,926	39.73	0.32	3.47	0.68
Run 3	a.m.+Midday+p.m.	1,081,136	6,859,230	193,039	35.53	11.66	117.60	23.74
Total	24-Hour	1,489,934	9,403,499	257,077	36.58	15.76	162.69	32.64
Run 4	a.m.	78,225	523,730	14,311	36.60	0.92	10.20	1.90
Hourly	Midday	91,174	557,188	14,884	37.44	0.92	9.23	1.95
	p.m.	144,467	848,063	29,992	28.28	1.62	15.39	2.71
	Night	31,700	197,803	4,975	39.76	0.33	3.74	0.73
Run	a.m.+Midday+p.m.	1,083,602	6,643,902	192,794	34.46	11.50	115.68	22.86
Total	24-Hour	1,495,702	9,215,341	257,469	35.79	15.78	164.18	32.39
Run 1	24-Hour	1,472,723	9,341,755	255,411	36.58	15.07	144.73	30.86

TABLE 7-16 Temperature by time period used in Runs 5 and 6

Period	Hours	Min. (°F)	Max. (°F)	Ambient (°F)
A.M. Peak	07:00-09:00	73.9	79.9	76.5
Midday	09:00-16:00	79.9	88.1	87
P.M. Peak	16:00-18:00	85.3	87.6	86.6
Night	18:00-07:00	73.6	85.3	76.5

temperatures in place of the average fall and spring temperatures. The results of this are shown in Table 7-20, with comparison of the 24-hr results of Runs 3 through 5.

Table 7-20 shows that using summer temperatures markedly increases the estimates of VOCs, with the result that Run 2 now has a higher estimate of VOCs than even the final version of Run 5, and Run 1 is only slightly lower than the final version of Run 5. Estimates of NO_x and CO both declined with the higher temperatures, resulting in estimates that now fall below those of Run 5. Given that the number of trips in the final version of Run 5 is about 3 percent higher than the number used for Runs 1 and 2, and that average speed drops by a little more than 1 mph, correction for these two effects and the concomitant increase in VMT will drive the Run 1 and Run 2 results even higher.

This analysis leads to the conclusion that simply using the standard transportation-planning estimates and applying summer temperatures will probably lead to incorrect estimates of emissions, with a tendency to overestimate VOCs in particular.

Run 6—Post-Processed Speeds

In Run 6, two steps were taken to improve the final speed estimates. First, when a traffic assignment is performed, the final iteration of a standard assignment uses as input the speeds from the preceding iteration of the assignment. These speeds are used in the computation of new minimum travel-time paths, and the volumes are reassigned. From the volumes assigned, link volumes and link V/C ratios are output. However, the travel times on the links are still those that were input to this assignment. Therefore, to complete the output data, the travel times should be recomputed using the final assigned volumes from an equilibrium assignment. This was the first step performed, using the standard BPR formula. This step affected VHT, while VMT remained the same as Run 5 for Summer Tuesday.

TABLE 7-17 Factors to convert spring/fall average weekday to summer peak day

Purpose	Seasonal Factor	Day Factor
Home-Based Work	0.94176	1.34561
Other	0.95823	1.01308

The second alternative was to use the V/C ratios from the end of the equilibrium assignment and to recompute the speeds using an alternative formula. After reviewing several alternative formulas and results obtained by other researchers from various formulas, it was decided to use the BPR formula with a 10th power replacing the 4th power, as shown in the following equation:

$$T_{iter} = T_0[1 + 0.15(v/C)^{10}]$$

In each case, the inputs used were those from the final version of Run 5 for Summer Tuesday, that is, with both seasonal and day-of-week factoring. This second step affected the speeds of individual links.

The results of Run 6 are shown in Table 7-21, with comparison to the preceding runs. The first run of BPR-4 showed small increases in speeds in the a.m. and p.m. peaks, which seems somewhat unexpected, but results from the fact that the final equilibrium run of the assignment provided a better routing than in the preceding run, with avoidance by some traffic of the most congested conditions. Hence, speeds appear to increase. The 24-hr and daylight period average speeds show concomitant increases. However, the BPR formula with the 4th power is known to overstate speeds, particularly on nonfreeway segments. Therefore, it is expected that the speeds estimated from this run should be too high. The result of the speed increases in the peaks showed up as decreases in VOCs for each of the peaks and the 24-hr and daylight periods; CO also decreased for each of the same periods; and NO_x increased slightly. All of these changes were as expected.

Re-estimating final speeds by using the 10th power (BPR-10) produced substantially different results, as expected. Speeds in the a.m. peak remained slightly higher than in the final version of Run 5, while midday speeds dropped, p.m. peak speeds dropped markedly, and night speeds dropped slightly. Average speed for the 24-hr period was the lowest of any estimate (30.02 mph, compared to a range of 35.39 to 37.44) and daylight period speeds also decreased to a lowest value of 27.49 mph (compared to a prior range of 34.46 to 36.64). The results of these speed changes were again as expected, with an increase of the VOCs to their highest total of 17.73 tons for the 24-hr period and 13.48 for daylight hours. CO also increased to 164.22 and 123.30 tons, respectively, while NO_x was marginally higher than the BPR-4 figures, but lower than several of the prior estimates.

TABLE 7-18 Results of Run 5 for each of seasonal and day adjustments

						Emissions (Tons)		
Source	Period	Trips	VMT	VHT	Avg. Speed	VOC	CO	NOx
Run 5 Summer Avg. Day Hourly	a.m.	74,563	499,906	13,608	36.74	0.82	7.63	1.66
	Midday	87,367	534,013	14,185	37.65	0.99	8.91	1.78
	p.m.	138,067	810,974	28,173	28.79	1.71	14.71	2.47
	Night	30,351	189,629	4,760	39.84	0.31	2.94	0.66
Run 5 Avg. Day Total	a.m.+Midday+p.m.	1,036,829	6,359,851	182,857	34.78	12.00	107.07	20.75
	24-Hour	1,431,392	8,825,028	244,737	36.06	15.96	145.29	29.33
Run 5 Summer Tuesday Hourly	a.m.	84,348	568,057	15,779	36.00	0.94	8.67	1.86
	Midday	90,280	553,814	14,784	37.46	1.03	9.22	1.84
	p.m.	149,287	885,642	32,337	27.39	1.93	16.62	2.69
	Night	32,145	202,243	5,096	39.69	0.33	3.13	0.70
Run 5 Tuesday Total	a.m.+Midday+p.m.	1,099,230	6,784,096	199,720	33.97	12.94	115.13	21.99
	24-Hour	1,517,115	9,413,255	265,968	35.39	17.17	155.83	31.11

These final results from Run 6 are compared with the prior runs, with the prorated figures for Runs 1 and 2 for the daylight period, in Figures 7-6 and 7-7. The graphs show the continuation in the climb of VOCs with disaggregation, with the final figure for 24-hr VOCs being 18 percent higher than the Run 1 figure, CO being 13 percent higher in the final run compared with the initial one, and NO_x being 3 percent higher in Run 6 with BPR-10 as compared with Run 1.

CONCLUSIONS OF THE AGGREGATION ANALYSIS

In the aggregation analysis reported here, several steps of disaggregation were attempted with the results from a typical MPO planning process. In this typical planning process, standard transportation-planning models were applied, with no explicit analysis of transit, which for the case study area

TABLE 7-19 Results of Run 5 with comparison to Runs 1–4

						Emissions (Tons)		
Source	Period	Trips	VMT	VHT	Avg. Speed	VOC	CO	NOx
Run 3 Total	24-Hour	1,489,934	9,403,499	257,077	36.58	15.76	162.69	32.64
	a.m.+Midday+p.m	1,081,136	6,859,230	193,039	35.53	11.66	117.60	23.74
Run 4 Hourly	a.m.	78,225	523,730	14,311	36.60	0.92	10.19	1.89
	Midday	91,174	557,188	14,884	37.44	0.92	9.22	1.95
	p.m.	144,467	848,063	29,992	28.28	1.62	15.37	2.70
	Night	31,700	197,803	4,975	39.76	0.33	3.73	0.73
Run 4 Total	24-Hour	1,495,702	6,643,902	192,794	34.46	15.78	164.18	32.39
	a.m.+Midday+p.m.	1,083,602	9,215,341	257,469	35.79	11.50	115.68	22.86
Run 5 Summer Avg. Day Hourly	a.m.	74,563	499,906	13,608	36.74	0.82	7.63	1.66
	Midday	87,367	534,013	14,185	37.65	0.99	8.91	1.78
	p.m.	138,067	810,974	28,173	28.79	1.71	14.71	2.47
	Night	30,351	189,629	4,760	39.84	0.31	2.94	0.66
Run 5 Summer Avg. Day Total	24-Hour	1,431,392	8,825,028	244,737	36.06	15.96	145.29	29.33
	a.m.+Midday+p.m.	1,036,829	6,359,851	182,857	34.78	12.00	107.07	20.75
Run 5 Summer Tuesday Hourly	a.m.	84,348	568,057	15,779	36.00	0.94	8.67	1.86
	Midday	90,280	553,814	14,784	37.46	1.03	9.22	1.84
	p.m.	149,287	885,642	32,337	27.39	1.93	16.62	2.69
	Night	32,145	202,243	5,096	39.69	0.33	3.13	0.70
Run 5 Summer Tuesday Total	24-Hour	1,517,115	9,413,255	265,968	35.39	17.17	155.83	31.11
	a.m.+Midday+p.m.	1,099,230	6,784,096	199,720	33.97	12.94	115.13	21.99
Run 1	24-Hour	1,472,723	9,341,755	255,411	36.58	15.07	144.73	30.86
Run 2	24-Hour	1,472,723	9,341,755	255,411	36.58	15.59	156.02	32.18

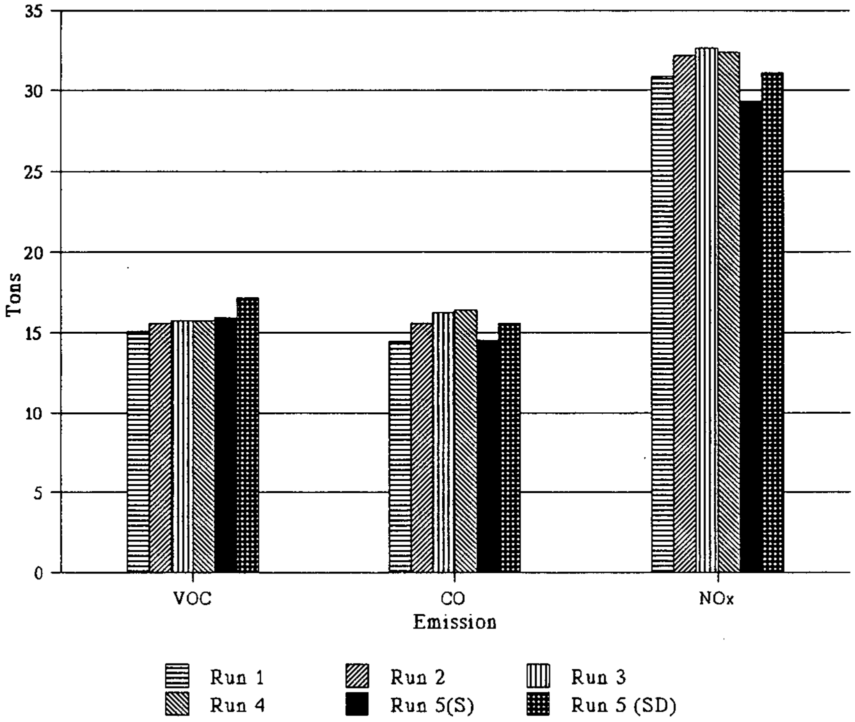

Figure 7-4. Comparison of total 24-hour emissions for Runs 1–5.

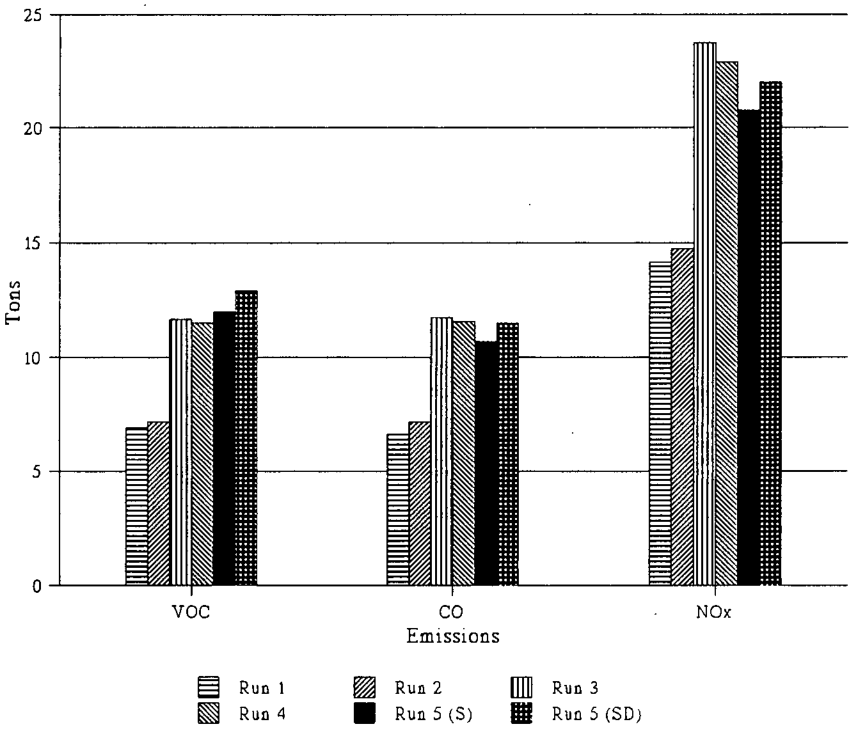

Figure 7-5. Comparison of daytime emissions for Runs 3–5.

TABLE 7-20 Results of Runs 1 and 2 with summer temperatures with comparisons to Runs 3–5

Source	Period	Trips	VMT	VHT	Avg. Speed	Emissions (Tons) VOC	CO	NOx
Run 3	24-Hour	1,489,934	9,403,499	257,077	36.58	15.76	162.69	32.64
Run 4	24-Hour	1,495,702	6,643,902	192,794	34.46	15.78	164.18	32.39
Run 5 (S)	24-Hour	1,431,392	8,825,028	244,737	36.06	15.96	145.29	29.33
Run 5 (SD)	24-Hour	1,517,115	9,413,255	265,968	35.39	17.17	155.83	31.11
Run 1	24-Hour	1,472,723	9,341,755	255,411	36.58	16.96	143.43	30.00
Run 2	24-Hour	1,472,723	9,341,755	255,411	36.58	17.22	151.76	30.63

Note: S indicates seasonal adjustment for summer, and SD indicates combined seasonal and day of week adjustment.

accounts for less than 1 percent of urban area trip making. The application used a mixture of default values for emissions estimation and locally derived values. As far as possible, the analysis was performed so as to replicate the typical methods that would be applied by most MPOs. A few MPOs would be expected to undertake a more sophisticated analysis process; however, most would be expected to perform analyses similar to the procedures described here for Run 1. Because the capability to estimate link-by-link emissions from a loaded network is not widely distributed in current transportation-planning software, sophistication of this type would generally require specific programming efforts using the output files from the assignment process.

The following facts emerge from this analysis:

- A crucial assumption in the transportation-planning process is the capacity of each link in the network. It became very clear in struggling to assign appropriate

TABLE 7-21 Results of Run 6 with comparison to Runs 1–5

Source	Period	VMT	VHT	Avg. Speed	Emissions (Tons) VOC	CO	NOx
Run 1	24-Hour	9,341,755	255,411	36.58	15.07	144.73	30.86
Run 2	24-Hour	9,341,755	255,411	36.58	15.59	156.02	32.18
Run 1 (Summer)	24-Hour	9,341,755	255,411	36.58	16.96	143.43	30
Run 2 (Summer)	24-Hour	9,341,755	255,411	36.58	17.22	151.76	30.63
Run 3 Post-Distribution Total	24-Hour	9,403,499	257,077	36.58	15.76	162.69	32.64
	a.m.+Midday+p.m.	6,859,230	193,039	35.53	11.66	117.6	23.74
Run 4 Post-Generation Total	24-Hour	9,215,341	257,469	35.79	15.78	164.18	32.39
	a.m.+Midday+p.m.	6,643,902	192,794	34.46	11.5	115.68	22.86
Run 5 Summer Avg. Day Total	24-Hour	8,825,028	244,737	36.06	15.96	145.29	29.33
	a.m.+Midday+p.m.	6,359,851	182,857	34.78	12	107.07	20.75
Run 5 Summer Tuesday Total	24-Hour	9,413,255	265,968	35.39	17.17	155.83	31.11
	a.m.+Midday+p.m.	6,784,096	199,720	33.97	12.94	115.13	21.99
Run 6 Speed-Processing (BPR-4) Summer Tuesday Hourly	a.m.	568,058	14,981	37.92	0.92	8.55	1.90
	Midday	553,814	14,784	37.46	1.03	9.22	1.84
	p.m.	885,642	25,856	34.25	1.68	14.41	2.78
	Night	202,243	5,096	39.69	0.33	3.13	0.70
Run 6 (BPR-4) Total	24-Hour	9,413,257	251,410	37.44	16.62	151.16	31.37
	a.m.+Midday+p.m.	6,784,098	185,162	36.64	12.39	110.47	22.25
Run 6 Speed-Processing (BPR-10) Summer Tuesday Hourly	a.m.	568,058	15,533	36.57	0.94	8.99	1.93
	Midday	553,814	18,503	29.93	1.09	9.96	1.87
	p.m.	885,642	43,108	20.54	2.00	17.81	2.82
	Night	202,243	5,136	39.38	0.33	3.15	0.70
Run 6 (BPR-10) Total	24-Hour	9,413,257	313,571	30.02	17.73	164.22	31.7
	a.m.+Midday+p.m.	6,784,098	246,803	27.49	13.48	123.3	22.58

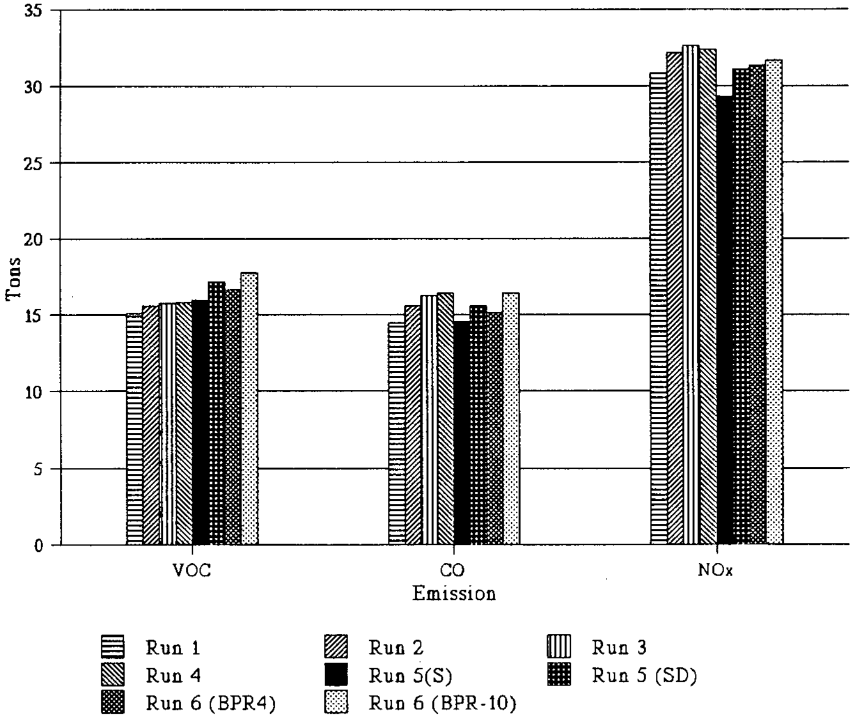

Figure 7-6. Comparison of total 24-hour emissions for Runs 1–6.

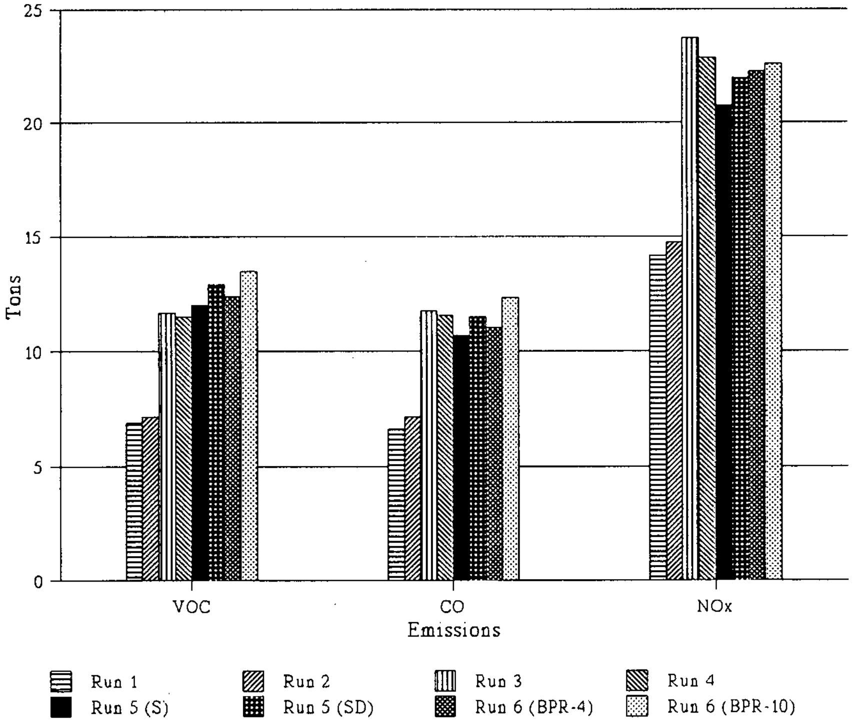

Figure 7-7. Comparison of daytime emissions for Runs 1–6.

capacities for hourly analyses considering that the decision on the actual capacity to code on a link can significantly affect the estimation of speeds and VMT, which are the primary ingredients of the emissions estimation.

- Those MPOs that have customarily used a 24-hr assignment, with capacities adjusted to produce estimates of the V/C ratios for the peak period, will be applying peak speeds to 24-hr VMT in estimating emissions. This refers to the practice of estimating 24-hr capacity of a link by multiplying its hourly capacity with a factor based on the K-factor. This may result in significant errors in the estimates of different pollutants. If plans are being assessed with most projects aimed at reducing peak-period congestion in order to reduce emissions, the effects of the projects may be seriously overestimated, because the speed improvements again occur entirely in the peak period but are applied to 24-hr VMT. Therefore, certain projects that succeed in reducing peak-period congestion, while having little effect on uncongested off-peak traffic, will have an exaggerated effect on regional emissions.
- Link-by-link estimation of emissions, using emission factors for 3 mph increments of link average speed, do not make a significant difference in estimates of emissions, although the values of the emissions show a consistent increase with disaggregation. (The use of 3 mph increments of link average speed is a feature of the EMIS program used for computation.)
- There are few differences in the results of applying diurnal factors immediately before traffic assignment and before trip distribution. However, differences will be larger the more congested the peak period is and the more that the trip-distribution changes and average trip lengths become different from peak to off-peak. Further, the addition of a mode-choice model in the modeling sequence is likely to show more profound differences between the two methods, although this could not be demonstrated in this case study.
- The effects of diurnal factoring are most apparent on the estimates of CO emissions. Effects are least on NO_x compared to the link disaggregation, and are a little greater on VOCs.
- The effects of summer temperatures alone are large, but tend to be mitigated by the reductions in trip making in the summer, compared to average spring and fall travel. More importantly, because of the temperature effects, combined with changes in VMT and speeds, the estimate of VOCs increases, while CO and NO_x both decrease. (These conclusions may not be valid for areas where summer traffic is higher than spring and fall travel.)
- The effects of using the peak day of the week instead of an average weekday is probably the most marked change found in this analysis. Increases in emissions of 5 to 8 percent were found in all three pollutants when the adjustment was made from an average summer weekday to the peak summer weekday.
- Speed post-processing, with a procedure such as BPR-10, produces a further addition to VOCs and CO, and, in this case, even resulted in a small increase in NO_x, apparently as a result of a greater range of speeds in the final assigned network with speed post-processing.
- The procedures investigated in this research are cumulative in their effects on VOCs, while CO and NO_x show increases for all changes through Run 3, following which NO_x estimates generally decline until Run 6, while CO declines after Run 4, until Run 6. In other words, the effects of summer temperatures and concomitant changes in VMT and speed generally are to decrease both CO and NO_x, while CO shows increases with the second method of diurnal factoring and NO_x does not. Speed post-processing, however, raises the estimates of all three pollutants.

RECOMMENDED RESEARCH

This research indicates that some important additional areas should be researched in order to illustrate completely the effects of transportation-modeling assumptions and procedures on emissions estimates. These effects are particularly important in understanding the effect on project planning and the development of long-range plans that affect peak-period congestion. These suggested areas of research are as follows:

- First, one step in the disaggregation procedure that was not undertaken (because procedures for doing it have not been sufficiently well developed for easy research) is the application of feedback in the entire modeling process. This should be researched to determine if the effects of feedback iterations that successively improve the estimates of travel times in the network also increase estimated emissions.
- Second, the issue of the capacity assumptions on links is of critical importance. Research is needed to determine the extent to which these assumptions affect the estimation of emissions, particularly with respect to obtaining appropriate estimates of levels of congestion. There is the potential to assign specific capacities to each link, rather than assigning capacities on the basis of functional class and area type. This is potentially feasible with networks based on geographic information systems and is being done by Oregon DOT for several of the smaller MPOs.
- Third, the effect on diurnal factoring when there is widespread traffic congestion on the network needs investigation. For this case study, traffic congestion was neither severe (V/C ratio greater than 0.95) nor widespread. Further, this case study did not use a mode-choice model and thus could not assess the effect of diurnal

factoring with a mode-choice model; this needs further investigation.

- Fourth, the effect of using speed increments of 3 mph for estimating link-by-link emission factors needs to be researched. This is a feature of the EMIS program.
- Fifth, seasonal and daily variations can substantially affect emissions estimates. Because this research used national averages for both, further research is warranted to determine the effects of locally derived adjustment factors.
- Finally, in this research, a one-speed post-processing procedure was applied and found to change emissions estimates significantly. Other post-processors have been tried in other studies and varying results have been found with respect to the realism of the speeds produced. Research is required to determine the most appropriate method to estimate link speeds under loaded conditions and to determine the effect of such speeds on emissions estimates.

CHAPTER 8

IMPROVED METHODOLOGIES FOR SELECTED PARAMETERS

INTRODUCTION

This chapter presents improved methodologies for developing selected travel-related inputs for the MOBILE5a model. Most MPOs can use the methodologies presented by using available resources. A few large MPOs use approaches and techniques similar to those discussed here. Other MPOs probably would see a substantial improvement in input data reliability if they used the recommended procedures.

OPERATING MODE FRACTIONS

Operating mode affects the emission rates of a vehicle. Operating mode is classified into three categories by the EPA, as follows: cold transient, hot transient, and hot stabilized. This variable was discussed in Chapter 2, and an analysis of the sensitivity of emission rates with respect to this variable was presented in Chapter 4. The physical measurement and determination of the operating mode of vehicles traveling on different roads is difficult—only a few attempts have been made. Another approach to determining operating modes is based on the elapsed time from a trip origin. The EPA's FTP cycle treats the first 505 sec of a trip as the transient mode—cold or hot. The difficulty in determining the elapsed time of vehicles on a roadway by field interviews can be overcome by an analytical approach. The traffic assignment technique of the stepwise travel demand modeling process can be enhanced to trace the elapsed time of interzonal trips assigned on the individual links of a network. The EPA (1977) and Ellis et al. (1978) used this approach; however, the scope of these analyses was limited and these were performed several years ago. A similar approach has been used by researchers at the University of Tennessee, Knoxville (UTK) to develop operating mode fractions by facility type and time of day. The findings of UTK studies are discussed in the following subsections. Although the analysis in this section uses 505 sec as the threshold or end of transient mode, the procedure can use any other time as the threshold (e.g., 200 sec).

Study on Operating Modes

Computer software for network analysis and traffic assignment—Traffic Assignment Program for Emission Studies (TAPES)—was developed by Venigalla (1994) with a special feature to trace and record the elapsed time of interzonal trips as they are assigned on each link along their path of travel. At the completion of the traffic assignment process, the assigned volume on a link can be classified into transient and stabilized modes on the basis of whether the elapsed time from origin exceeds 505 sec or not. The popular travel modeling software MINUTP and EMME/2 also have this capability, but their use in developing operating mode fractions has been limited. Venigalla tested his software with travel and network data for Charlotte, NC, and found that operating modes varied considerably by functional class of roadways, location of a roadway facility within an urban area, and the time of day of travel.

Start Modes of Trips

The special traffic assignment techniques mentioned above require input data on the start mode of the trips, because the interzonal trips being assigned on a network have to be stratified at the beginning of the process into two groups—cold-start and hot-start groups. (The assignment technique differentiates only between the transient modes and the stabilized mode.) This information is not readily available, although it is commonly known that cold-start fractions vary according to trip purpose and time of day. For example, it is reasonable to expect many home-based work trips in the morning to start in the cold mode. Venigalla et al. (1995) analyzed data available from the NPTS to develop fractions of trip ends in cold and hot starts, respectively. The NPTS compiled detailed data on the chain of trips made by individuals, including the times of each trip start and trip length. Using the EPA's standards for the soak period associated with cold and hot starts for catalyst and noncatalyst vehicles, the researchers were able to determine the start mode of each trip.

Operating Modes

The methodology that was tested with data from Charlotte, NC, was applied by UTK researchers in a comprehensive manner to the case of Sacramento, CA. This study, sponsored by California DOT (CALTRANS), included all types of trips—internal and external—for a typical weekday of 1990.

The start modes of trips were assumed to follow the pattern identified from NPTS data (Venigalla et al., 1995). The time of travel was recognized, and the trips were grouped into the following four periods:

- Morning: 6:00 a.m. to 10:00 a.m.;
- Mid-Day: 10:00 a.m. to 5:00 p.m.;
- Afternoon/Evening: 5:00 p.m. to 9:00 p.m.; and
- Night: 9:00 p.m. to 6:00 a.m.

The roadway links were classified according to the functional class as well as location in the urbanized area, except for local roads that could not be stratified by location. The major findings of this study for the morning period are presented in Tables 8-1 through 8-3. The data in Table 8-1 show that the cold-transient fraction on local roads during the morning is 55.53 percent, whereas that on freeways is only 15.18 percent. Similar wide variations can be found for different locations (Table 8-2). Chatterjee et. al. (1995) report results for the other periods.

The results of the Sacramento study show that operating mode fractions vary considerably according to the functional class of facilities and their location as well as the time of day. The results are compatible with what may be expected intuitively. However, the state of the practice is to use the default values of operating mode fractions, which are 20.6 percent for cold-transient mode, 27.3 percent for hot-transient mode, and 52.1 percent for hot-stabilized mode. What is not known is how much difference in emissions estimates may be caused by the use of the default values for all types of facilities instead of more stratified and refined values as developed for Sacramento. This difference would depend on the scope of a study—whether it is areawide or project oriented. Ideally, each urbanized area should develop operating mode fractions of its own in a similar manner as done for Sacramento.

VMT ON LOCAL ROADS

The current VMT estimation procedures underestimate travel on local roads. This is a serious problem because, during certain times of the day, travel on local roads occurs in the cold-transient operating mode for which emission rates are relatively high, and thus relatively limited mileage traveled on local roads generates greater emissions. Suggestions for improving estimation of local road VMT follow.

TABLE 8-1 Operating mode fractions by functional class for the 6:00 a.m.–10:00 a.m. period

	Transient Mode		
Functional Class	Cold (%)	Hot (%)	Hot Stabilized (%)
Freeways	15.18	6.11	79.71
Expressways	30.05	10.66	59.29
Major Arterials	41.51	15.23	43.26
Minor Arterials	39.87	13.42	46.71
Collector	48.56	15.65	35.79
Freeway Ramps	31.67	11.99	56.34
Local Roads	55.53	18.56	25.91
All Roads	29.70	10.73	59.57

TABLE 8-2 Operating mode fractions by functional class for the 6:00 a.m.–10:00 a.m. period

	Transient Mode		
Functional Class	Cold (%)	Hot (%)	Hot Stabilized (%)
CBD	29.23	11.81	58.96
Fringe	32.99	12.42	54.59
Outlying Business District	44.23	14.64	41.13
Suburban	34.19	12.37	53.44
Rural	14.94	5.98	79.08
All Areas	29.70	10.73	59.57

Note: Local road VMT could not be stratified by location. The percentages for specific locations do not include local road VMT. The percentages of all areas combined do include local roads.

Network-Based Travel Modeling

The network of roadways commonly used for the stepwise travel modeling process usually does not include all roads in the planning area. All arterials and collectors are included in the network; however, local roads are not included and are represented by "centroidal connectors," which are hypothetical links that connect each zonal centroid to collector roads. The traffic assignment process assigns *interzonal* trips and yields traffic volumes on these centroidal connectors; thus the VMT attributable to *interzonal* trips can be calculated on the basis of these assigned volumes and the coded lengths of these links.

Planners should be particularly aware of two issues involving the VMT estimated for centroidal links by the traffic assignment procedure. The first issue involves the lengths of these connectors and links. Although the lengths of these centroidal links do not adequately represent the total local road mileage within a zone, the *interzonal* traffic volumes assigned on these links represent the aggregate volumes of many local roads found within the zone. In other words, although smaller traffic volumes occur on several different local roads within a traffic zone, the network assignment shows a higher volume on a shorter length of a link. Thus, if the length of a centroidal link is estimated carefully on the basis of the size of a zone, the VMT on this link can be accepted as the local road VMT attributable to *interzonal* travel. Most of the traffic assignment programs report this VMT on centroidal links and connectors.

The second issue is that the assigned volumes on the centroidal links do not include *intrazonal* travel, which is not handled by the traffic assignment process at all, although

TABLE 8-3 Operating mode fractions by functional class and location for the 6 a.m.– 10:00 a.m. period

	Location				
Functional Class	CBD	Fringes	Outlying Business District	Suburban	Rural
Freeways	28.49	31.97	22.97	18.86	7.23
Expressways	-	25.31	51.17	42.77	3.38
Major Arterials	30.65	48.57	53.40	46.92	24.44
Minor Arterials	31.51	36.79	57.32	47.76	29.70
Collectors	41.16	42.28	58.71	47.39	35.92
Freeway Ramps	33.81	37.06	53.06	38.21	36.20

Note: This list does not include results for local roads because local roads could not be stratified by location. For overall operating mode fractions on local roads, see Table 8-1.

these trips are included in the trip tables. The VMT generated by *intrazonal* trips within a zone can be estimated by using the *intrazonal* trips for that zone available from trip tables and multiplying by a distance representing the average *intrazonal* trip. This distance would vary on the basis of the size of a particular zone. A transportation planner has to examine the size and land use pattern for each zone and estimate an appropriate distance for *intrazonal* trips for each zone. Additional off-model calculations have to be done to capture this VMT.

The VMT on centroidal links generated by *interzonal* trips combined with the VMT generated by *intrazonal* trips would represent the local road VMT. Thus, local road VMT can be estimated using the results of network-based traveling modeling used for urban transportation planning studies. It does, however, require extra effort by transportation planners.

Highway Performance Monitoring System Approach

An alternative to network-based travel modeling for VMT estimation is the HPMS developed by FHWA. Each state DOT is required by FHWA to report VMT in each urbanized area along with rural areas and small urban areas for each functional class of roads. FHWA specifies a sampling scheme for developing VMT estimates for all functional classes except rural minor collector, rural local, and urban local roads, and the procedure for estimating VMT on these three classes of roads is left to each state DOT. Thus, the state DOTs have no standard procedure to estimate the local road VMT, which they report for each urbanized area. Recently, FHWA examined this issue in *Traffic Estimating Procedures for the Local Functional System* (Mergel, 1993). This research concluded that the best approach for estimating local road VMT for HPMS is a count-based procedure and presented a sound sampling scheme for this purpose.

The accuracy of VMT estimates based on HPMS data largely depends on the sampling scheme and sample size. Until a specific sampling plan is actually adopted for local road VMT, the expected accuracy of the procedure cannot be assessed.

Simplified Procedures

There are a few simplified approaches to estimating local road VMT. One of these approaches is to use a "percentage" value of local road VMT with respect to the total VMT. It is widely accepted that in urban areas the VMT on local roads accounts for approximately 12 to 17 percent of the total VMT. A value within this range may be selected and can be combined with the VMT estimated for all other classes of roads to estimate the total VMT using simple arithmetic. For example, if 15 percent is considered an appropriate value for local road VMT, then the other VMT, that is, VMT on roads other than local, can be divided by 0.85 to obtain the value for total VMT; and 15 percent of the total will represent local road VMT.

Another technique is applicable if the mileage of local roads is known fairly accurately. The local road mileage can be stratified into three or four groups according to expected traffic volumes. Then an average traffic volume may be assumed for each group, and the VMT for each group can be estimated on the basis of this average volume and the mileage. These volumes ideally should be based on sample counts. This approach is similar to the HPMS procedure used for the other classes of roads.

The accuracy of the above two procedures can be questioned; however, if sufficient care is taken in making the assumptions needed by these procedures, acceptable estimates of local road VMT can be developed fairly quickly.

IMPROVED SPEED ESTIMATION METHODS

To improve speed estimation, reliable information on traffic volumes and roadway characteristics is necessary. Traffic volumes are generated either directly through count programs (such as HPMS) or indirectly by travel forecasting models. Improvements in both of these areas, which are of value for purposes other than air quality planning, are ongoing. For example, FHWA recently expanded the sampling requirements for HPMS to include the donut area outside of urban area boundaries but within the airshed. Also, local areas are installing advanced traffic control systems as part of the Intelligent Transportation System (ITS) effort. These systems can count traffic continuously at many different locations, a capability not previously affordable. On freeways, these systems also can monitor speeds directly. (The forecasting of speeds still must be done synthetically, however.) Similarly, FHWA has initiated the Travel Model Improvement Program, which offers improved travel forecasting procedures. Improvements in highway capacity analysis is ongoing and should provide a better basis for estimating speeds.

Despite progress and even with improved base data (i.e., volumes and capacities), most methods in use do not adequately estimate vehicle speeds under congested conditions. Uncongested freeway speeds can be estimated accurately; however, these conditions are of less concern in those areas experiencing significant air quality problems. On arterials, the prediction of even uncongested speeds is difficult and must incorporate information on signal characteristics (e.g., signal density) in addition to volume. Because the speeds output by travel forecasting models are too crude to be used directly, some type of post-processing appears to be the best way of refining speeds. However, methods such as that described in the *Highway Capacity Manual* or the standard BPR curve and its variants do not address the temporal and spatial aspects of congestion. That is, these procedures only consider the effects of congestion at one point in time and space. In reality, traffic queues that build during congestion can spread to adjacent roadway sections and time periods. The best analytic methods available to study these effects are the microscale traffic simulation models, FRESIM and NETSIM. However, these models are extremely data and runtime intensive and cannot feasibly be applied to large networks. Current research sponsored by FHWA may yield better methods.[1] The FHWA study is developing simplified procedures on the basis of the microscale simulation models. NCHRP Project 7–13, "Quantifying Congestion," also may provide a methodology that can be applied to air quality planning. Finally, the recently initiated NCHRP Project 3–55(2), "Techniques to Estimate Speeds and Service Volumes for Planning Applications," may provide additional improvements. These three studies, along with the methods reviewed in this report, should provide a wide variety of useful techniques. Before a totally new speed estimation methodology is initiated, existing methods should be validated in the field to provide a level of user confidence. The methods should be tested using a case study approach where one or two local areas are selected for study. In these areas, the local travel models and HPMS data, as well as empirical measurements of speed, should be used to establish baseline conditions. (Those areas that have developed CMSs should have a speed and delay field data collection program.) Each of the speed estimation methodologies can then be applied to available data and compared to the empirical speed measurements.

In addition to developing better speed estimation procedures for the current MOBILE5a model framework, consideration should be given to the inputs required by the next generation of emissions models, "modal emission models," so named because they predict emissions as a function of specific vehicle modal activity (acceleration, deceleration, cruise, and idle) instead of average route speed. Many researchers believe that the current practice of measuring emissions over an entire trip is inadequate because the vehicle events that cause high emissions are masked within the driving cycle. The recently initiated NCHRP Project 25–11, "Development of a Modal-Emission Model," is an attempt to develop a modal-based emission model. If such models are accepted into practice, developing transportation inputs will become even more difficult: instead of simply predicting average travel speeds, transportation analysts would be required to estimate the amount of each modal activity. In the ideal situation, models that predict vehicle modal activity on detailed networks can be bundled with modal emissions relationships so that the two operations are performed simultaneously; however, such a combined framework is not feasible in the short term. When modal emissions models become available, it will be necessary to develop analytic procedures that allow prediction of vehicle modal activity from available data. Two approaches offer promise and are discussed below.

Detailed Observations of Real-World Driving Patterns

Several chase car and instrumented vehicle studies have been conducted that reveal the speed and acceleration profiles of vehicles. In addition, data available from the CARB and the EPA also might be used to develop the profiles of operating mode frequencies. These mode profiles can be used in various evolving emissions modeling approaches from multiple-cycle approaches to true load-based modal models. For example, a proposed 25-bin modeling approach involves the development of five different emission testing cycles for each of five different roadway classes. Each cycle could be designed to better reflect typical vehicle activity on five roadway classifications (i.e., freeways, expressways, arterials, collectors, and local roads) under five congestion

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[1] This project, *Diurnal Traffic Distribution and Daily, Peak, and Offpeak Vehicle Speed Estimation Procedures for Air Quality Planning*, is sponsored by the Office of Environment and Planning.

levels (Guensler, 1994). Operating mode frequency profiles could be determined for each of the 25 driving cycles of the 25 bins and used as default profiles in the modal emissions model developed under the research project. Modal activity patterns could then be "backed out" from the driving cycles in each bin. However, substantial problems with collecting modal activities in the real world would be likely. The most obvious would be the ability to capture a wide range of driver activity that encompasses all driver types. More important, however, would be the ability to capture the precise traffic conditions that the vehicle is subjected to at the precise time of modal activity. One previous study, using a laser range finder, attempted to collect visual estimates of vehicle density to relate to modal activity, but review of these data show that this method is very inaccurate. For example, the speed range shown for LOS F ("stop-and-go" traffic conditions) from this study is very wide, ranging from 0 to 55 mph.

Application of Microscopic Simulation Models

As shown in Figure 8-1, TRAF (consisting of FRESIM and NETSIM) can be used to relate vehicle modal activity to traffic conditions. FRESIM and NETSIM simulate the speed and acceleration of individual vehicles on a second by second basis. Therefore, by developing the appropriate output formats, one can summarize modal activity for each link in the test network. However, because TRAF uses a standard set of vehicle performance equations and driver characteristics, it does not capture the full range of variability in speeds and accelerations that can be observed on-road. For example, although it produces close estimates of average speed on a link for a given set of conditions, the variance of speeds is much lower in TRAF than in the real world. Therefore, the observational studies listed above can be used to calibrate the internal TRAF relationships to more closely reproduce real-world driving behavior. (With the simulation approach, field studies' problems with matching vehicle activity to specific traffic conditions in time and space is circumvented; field studies will be used to indicate the true range of speeds and accelerations that TRAF should be replicating.) Once this is done, an experiment can be designed that controls for exogenous factors such as congestion (V/C), grade, and facility type. The advantages of using this approach is that data from every vehicle in the network are captured and the LOS is tightly controlled for the observation period. (Traffic patterns are widely variable from one minute to the next on real highway segments.) Optionally, the results of the simulation experiments can be incorporated into a network post-processor in the same way that speed post-processors operate.

VEHICLE CLASSIFICATION (VMT MIX)

The purpose of the vehicle mix input within the MOBILE5a model is to develop the composite vehicle emissions factor as a weighted average of the eight MOBILE5a vehicle types. However, a major discrepancy exists between the MOBILE5a vehicle types and the FHWA vehicle types (13 classes) available to transportation analysts. MOBILE5a vehicle classes are based on engine fuel and weight, while the FHWA types are based on the number of axles and vehicle configuration (e.g., trailer articulation). Therefore, a procedure must be developed to convert from one type to another. The EPA has developed a method that converts FHWA types to MOBILE5a types but not vice versa (Table 8-4). This method was developed on the basis of the default MOBILE5a VMT mix fractions and the American Automobile Manufacturers Association's estimates of the diesel-gasoline split in annual sales of some vehicle classes over the past few years.

However, the research team decided to pursue an alternative method that reflected the original proposal. For developing conversions in both directions for trucks, the team used the 1987 Truck Inventory and Use Survey (TIUS) from the Census Bureau as the data source. The TIUS is a stratified random sample sent to registered truck owners that collects information on the physical and operating characteristics of the truck. Because the TIUS contains information on gross vehicle weight (GVW), axle configuration, and engine fuel, it can be used to develop truck conversion percentages directly. Each truck in the sample was assigned both a MOBILE5a and FHWA vehicle type. The VMT for each truck was then calculated, expanded by the sample expansion factor, and tabulated.

To supplement the TIUS for passenger car conversions, the research team used the *Transportation Energy Data Book* (Davis and Strang, 1993) to estimate the diesel-gasoline split. Estimation of the bus conversion from the FHWA type to the MOBILE5a type was accomplished as shown in Table 8-5. The bus conversion in the opposite direction is complicated because the HDDV and HDGV categories are also occupied by truck types. The TIUS VMT for trucks and the bus VMT from Table 8-5 can be used to estimate the split of FHWA vehicle types in the HDDV and HDGV categories. However, TIUS VMT for single-unit trucks (six-tire and higher) and combination trucks have been historically lower than VMT estimates from other sources. To account for this discrepancy, the TIUS VMT for the calculation of the HDDV and HDGV only was increased by the ratio of total 1987 VMT from *Highway Statistics* (FHWA, 1987) to the 1987 TIUS VMT (Table 8-6). This was done to avoid overestimating the bus VMT in these categories by providing a better match between the VMT estimation methods. The final conversion factors are shown in Tables 8-7 and 8-8. These conversion factors are substantially different from those developed by the EPA (Table 8-5) for single-unit trucks and buses. However, use of the TIUS-developed conversion factors is recommended because of the widespread use of the TIUS in highway planning. Although TIUS estimates of total VMT have been considered to be low, the relative share of VMT

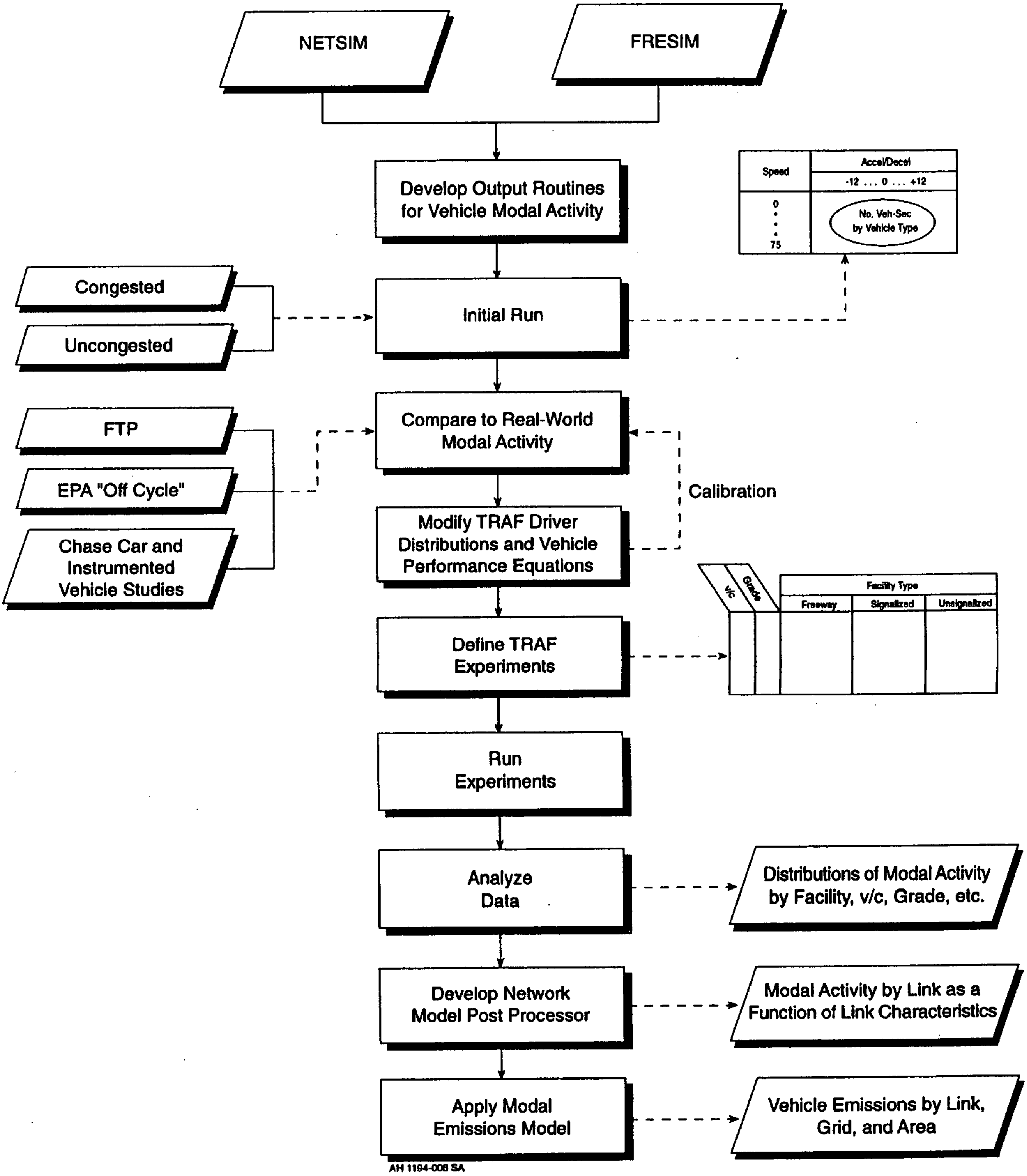

Figure 8-1. TRAF simulation process.

TABLE 8-4 EPA-derived conversion of vehicle types

FHWA Category	MOBILE5a Category
Motorcycle	MC
Passenger Car	98.64% LDGV, 1.36% LDDV
Other 2-Axle, 4-Tire Vehicles	65.71% LDGT1, 33.47% LDGT2, 0.82% LDDT
Buses	10.28% HDGV, 89.72% HDDV
Single-Unit Trucks	
2-Axle, 6-Tire	87.90% HDGV, 12.10% HDDV
3-Axle	50.00% HDGV, 50.00% HDDV
4 or More Axle	50.00% HDGV, 50.00% HDDV
Single Trailer Trucks	
4 or Fewer Axle	HDDV
5-Axle	HDDV
6 or More Axle	HDDV
Multi-Trailer Trucks	
5 or Fewer Axle	HDDV
6-Axle	HDDV
7 or More Axle	HDDV

TABLE 8-5 Conversion of FHWA "bus" vehicle type to MOBILE5a vehicle types

Bus Category	MOBILE 5a Type	Assumed Percentage[1]	1987 VMT	VMY Percentage
Commercial	HDDV	100	3,728[2]	38.41
Transit	HDDV	100	2,079[3]	21.41
School	HDDV	50	1,950[4]	20.09
	HDGV	50	1,950[4]	20.09
Total			9,707	

[1] Based on conversation with Stacy Davis of Oak Ridge National Laboratory.

[2] National Transportation Statistics: Annual Report, Bureau of Transportation Statistics, September 1993.

[3] Davis, S. C., and S. G. Strang (1993). *Transportation Energy Data Book*, Edition 13. Oak Ridge National Laboratory, Oak Ridge, TN.

[4] This study is called *Quantifying Congestion*.

TABLE 8-6 Procedure for estimating the MOBILE5a-to-FHWA vehicle type conversion for HDDV and HDGV

TIUS-Based	2A4T	Bus	2A6T	3A	4+A	3/4ASing.	5ASing.	6+ASing.	4/5AMulti.	6AMulti	7+AMulti.	Total
HDGV VMT	2,603	1,950	14,404	939	63	667	430	29	0	-	-	26,083
HDDV VMT	2,786	7,757	7,763	5,518	1,300	12,307	42,065	3,016	2,182	304	206	85,204
HDGV (Adjusted)	7,318	1,950	19,588	1,277	85	940	606	41	0	-	-	31,805
HDDV (Adjusted)	2,681	7,757	10,557	7,504	1,768	17,355	59,317	4,253	3,077	429	2911	14,988
HDGV (Row %.)	23.01	6.13	61.59	4.02	0.27	3.96	1.90	0.13	0.00	0.00	0.00	100.00
HDDV (Row %)	2.33	6.75	9.18	6.53	1.54	15.09	51.59	3.70	2.68	0.37	0.25	100.00

Notes: Adjustments based on ratio of VMTs from *Highway Statistics* and TIUS for 1987. Adjustment factor for single units (6-tire and higher) = 1.3599. Adjustment factor for combinations = 1.4101.

TABLE 8-7 Conversion factors for FHWA and MOBILE5a vehicle types

MOBILE5a Vehicle Type	Motor-cycles (Row %)	Passenger Cars (Row %)	2 Axle, 4 Tire Single Units (Row %)	Buses (Row %)	2 Axle, 6 Tire Single Units (Row %)	3 Axle Single Units (Row %)	4+ Axle Single Units (Row %)	3/4 Axle Single Trailer (Row %)	5 Axle Single Trailer (Row %)	6+ Axle Single Trailer (Row %)	4/5 Axle Multi Trailer (Row %)	6 Axle Multi Trailer (Row %)	7+ Axle Multi Trailer (Row %)
Motorcycles	100.00	-		-	-	-	-	-	-	-	-	-	-
LDGV	-	100.00	-	-	-	-	-	-	-	-	-	-	-
LDDV	-	100.00	-	-	-	-	-	-	-	-	-	-	-
LDGT, ≤6K	-	-	99.21	-	0.78	0.01	0.00	0.00	0.00	0.00	-	-	-
LDGT, 6-8.5K	-	-	85.81	-	14.15	0.00	0.03	0.01	-	-	-	-	-
HDGV	-	-	23.01	6.13	61.59	4.02	0.27	2.96	1.90	0.13	-	-	-
LDDT, ≤8.5K	-	-	95.87	-	4.02	0.01	0.04	0.01	0.05	-	-	-	-
HDDV, >8.5K	-	-	2.33	6.75	9.18	6.53	1.54	15.09	51.59	3.70	2.68	0.37	0.25

TABLE 8-8 Conversion factors for MOBILE5a FHWA vehicle types

FHWA Vehicle Type	Motorcycle (Row %)	LDGV (Row %)	LDGT (Row %)	LDGT ≤6K (Row %)	6-8.5K (Row %)	HDGV (Row %)	LDDT ≤8.5K (Row %)	HDDV >8.5K (Row %)
Motorcycles	100.00	-	-	-	-	-	-	-
Passenger Cars	-	98.80	1.20	-	-	-	-	-
2 Axle, 4 Tire Single Units	-	-	-	90.62	3.99	1.76	2.99	0.65
Buses	-	-	-	-	20.09	-	79.91	-
2 Axle, 6 Tire Single Units	-	-	-	10.69	9.92	50.36	1.89	27.14
3 Axle Single Units	-	-	-	0.71	0.01	14.44	0.01	84.83
4+ Axle Single Units	-	-	-	0.06	0.45	4.56	0.36	94.57
3/4 Axle Single Trailer	-	-	-	0.06	0.02	5.13	0.01	94.77
5-Axle Single Trailer	-	-	-	0.00	-	1.01	0.02	98.97
6+Axle Single Trailer	-	-	-	0.00	-	0.95	-	99.05
4/5 Axle Multi Trailer	-	-	-	-	-	-	-	100.00
6-Axle Multi Trailer	-	-	-	-	-	-	-	100.00
7+Axle Multi Trailer	-	-	-	-	-	-	-	100.00

across trucks in the TIUS sample is consistent, thus making it an appropriate basis for the conversion factors. The conversion factors provide a quick method for state and local analysts to convert their own vehicle classification data to MOBILE5a classes. The analysis in Chapter 5 showed that substantial variation exists in vehicle mix among the different highway functional classes. Therefore, the distributions in Chapter 5 may be used by planners as alternatives to the MOBILE5a default values when analyses are conducted at the functional class level. The values in Chapter 5 are based on recent data from FHWA's Truck Weight Study. Future studies should provide additional information on this subject.

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CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

MAJOR FINDINGS

This research study examined various methodologies and issues related to errors associated with estimates of emissions from mobile sources on the basis of EPA's MOBILE5a model; these topics can be grouped into two broad categories—methodologies for estimating travel-related input variables for MOBILE5a and the sensitivity of MOBILE5a's emissions factors with respect to these travel-related factors. The findings of these two categories of topics are discussed below.

Methodologies for Travel-Related Input Variables

Errors and variations in emissions estimates often result from the methodologies used for estimating the input variables. A thorough review of the literature and a survey of a sample of state DOTs and local MPOs indicated that various methodologies of varying complexity are being used for every travel-related variable. The level of sophistication of methodologies employed by an agency depends on the resources available at the agency. For example, large MPOs with experienced staff are more likely to use refined procedures, such as speed feedback loops, in their travel demand modeling process and/or a post-processing method for estimating link speeds than are small MPOs. The estimated values for link speeds obtained from travel demand models can vary substantially, depending on the procedure used. Most of the travel speed estimation methods do not include the effect of traffic congestion on upstream locations. With the exception of microscale traffic simulation models, none of the methods adequately assesses the buildup and dissipation of vehicle queues over time and space. Because most urban areas that experience air quality problems also experience severe traffic congestion, the need for accurate procedures for estimating travel speeds under congested traffic conditions is critical.

The estimated value of total/areawide VMT obtained from a network-based travel demand model for an urbanized area can be considerably different from that obtained from HPMS. Several urban areas have had difficulties in reconciling the difference in the results of these two methods of estimating VMT.

For a few variables, many urban areas use EPA-provided default values. These include VMT mix and operating mode fractions. In reality, the distribution of vehicle types in the traffic stream varies substantially across highway classes in general and even within a particular highway class, depending on the characteristics of the location and the time of day. The same is true for operating mode fractions. Improved methodologies are needed for these variables, and this research presents some alternatives for improvement in Chapter 8.

Another methodology-related issue involves inconsistencies in the way the stepwise travel demand modeling process is implemented by different agencies. A case study for Baton Rouge, LA, was carried out to determine how different aggregation schemes may affect the results of modeling. These aggregation schemes included feedback loops for speeds, diurnal factoring of trips, speed post-processing after traffic assignment, and estimation of emissions on the basis of individual links versus groups of links.

The aggregation analysis presented in Chapter 7 demonstrated that the different schemes for organizing the modeling process can have a substantial effect on emissions estimates. This case study also produced other important findings. One of the crucial tasks of the travel demand modeling process is the determination of the capacity of each link of the road network. The actual capacity values coded can have extraordinarily large effects on the estimation of speeds and VMT, which are the primary ingredients of emissions estimation. An extremely important finding of this study is that many agencies use, for a link's 24-hr capacity, a value calculated by adjusting its hourly capacity by a K-factor-based multiplier. This practice results in 24-hr V/C ratios that resemble peak-hour V/C ratios, and thus the link speeds generated by this procedure for use in conjunction with 24-hr VMT are, in effect, peak-hour speeds. This may result in significant errors in the estimated values of different pollutants, such as VOCs, CO, and NO_x. Although the findings of the Baton Rouge case study may not apply to every case, they are valid for many nonattainment areas that do not have the resources to use advanced analytical procedures for travel demand modeling and emissions calculations.

MOBILE5A EMISSIONS FACTORS

An important contribution of this study was the demonstration of the results of combining different sources of variations and errors. A traditional sensitivity analysis, presented in Chapter 4, showed that even low estimates of errors associated with transportation-related input variables can produce variations in the emission rates of MOBILE5a of ±15 percent. For agencies that do not use rigorous procedures for estimating transportation inputs to MOBILE5a, the compounded error or variation in emission rates because of errors associated with multiple transportation variables can be nearly ±40 percent. The pattern of combined error with respect to the directions of individual errors was examined—no clear pattern was found to exist. Individual errors of mixed sign do not necessarily dampen the combined effect.

Another analysis, presented in Chapter 6, examined the error or uncertainty involved with the calibration of the SCFs of MOBILE5a. This analysis used the same data used by the EPA to develop the SCFs of MOBILE5a for light-duty vehicles. It was determined that the use of the SCFs themselves, which are embedded within the model, result in significant uncertainty in emission rate output. The confidence intervals of emission rates were found to be very wide, especially for CO. The fleet CO emission rates for the case of a congested freeway (average speed 16 mph with zero standard deviation) was predicted to be 24.6 grams per mile; the 95 percent confidence interval was between 19 and 72 grams per mile. The exhaust HC emission rate for this case was 2.1 grams per mile, and the 95 percent confidence interval was between 1.8 and 3.4 grams per mile. Another case examined was that of a congested nonfreeway arterial (average speed 8 mph with zero standard deviation). The fleet CO emission rate for this case was 40.4 grams per mile; the 95 percent confidence interval was between 24 grams per mile and 341 grams per mile. The exhaust HC emission rate for this case was 3.9 grams per mile; the 95 percent confidence interval was between 2.6 and 12.3 grams per mile. These results represent the distributional analysis of a single source or component, namely SCFs. Additional uncertainty is inherent in the use of temperature and other internal correction factor algorithms of MOBILE5a. (These confidence intervals cannot be converted to "± percent error" because the distributions are skewed.)

The combined effect of uncertainty or error associated with input average speed and that associated with SCFs was analyzed. The effect of the standard deviation of input average speed on emission rates was much smaller than that of the internal SCFs, and thus the combined effect was mostly attributable to the SCFs. There is as much, if not more, need for improving the internal accuracy of the MOBILE5a model itself as for improving the accuracy of external inputs to the model.

CONCLUSIONS

1. There are several methods of improving the accuracy of transportation and emission factor inputs. For example, the estimation of both VMT and speed data can be improved with the use of time-of-day stratification; feedback loops; speed post-processing; and better base data related to such items as the coverage of the actual road network represented in network analysis, more accurate time-of-day factors, and estimation of realistic free-flow speeds. Similarly, detailed values for operating mode fractions can be developed by using a special feature of the traffic assignment technique that traces the elapsed time of trips from the origin. However, the application of these advanced techniques requires experienced personnel not available at many MPOs. Transportation researchers can provide help by performing more case studies and developing detailed guidelines about the methodologies to be used for different cases and situations. The complexity of a methodology must be matched with resources available at an agency and the purpose or goal of an analysis.
2. The current methodologies for estimating travel-related inputs for MOBILE5a are useful, even though these are not as accurate as users may wish. The users of the results, however, have to recognize and assess the wide range of potential errors. With the help of the current models, a planner can assess if a project being considered is in the right direction with regard to improving air quality and which projects among many are likely to be more beneficial. However, further research is needed to develop a more accurate picture of the uncertainty related to different variables and the resulting emissions estimates.
3. Until more refined procedures are available, practitioners should recognize that emissions estimates will have a wide range of variability. Therefore, these estimated values should be used carefully when predicting attainment classification and conformity determination for either areawide or project-level impact assessments. The probability of errors in the absolute values of emission estimates should be recognized by planners, regulators, and decision-makers. Transportation researchers can help by identifying the potential range of variability and by developing appropriate procedures to minimize these errors.

RECOMMENDED RESEARCH

Several areas for further research were identified during this study. The order of the recommended research items are not in order of their importance.

1. Sensitivity analysis of emission estimates using alternative approaches for estimating VMT and travel speed. The commonly used procedure for estimating VMT and speed is link-based. This approach estimates VMT and speed for each link and then aggregates these in some manner. However, MOBILE5a's approach to applying speed is trip-based. An FHWA study has shown that these two approaches produce different results. Further, the research team recognizes that the location of the emissions is a problem under the trip-based approach. More case studies are needed. The

trip-based approach uses trip tables, distance skim trees, and travel time skim trees to estimate VMT generated by interzonal trips and the corresponding average travel speeds. This research will include procedures for identifying the area where the emissions originate.

2. Sensitivity analysis of emission estimates using aggregated and desegregated operating mode fractions. Most metropolitan areas use the default operating mode fractions on the basis of the FTP cycle because it is difficult to determine project-specific values. However, a recent study (based on data for Sacramento, CA) has shown considerable variation of operating mode fractions by functional class of roadways, location, and time of day. The effect of these different values on estimates of emissions should be assessed at the areawide and subarea levels.
3. Accuracy of different methods of estimating local road VMT. Several different approaches for estimating VMT on local roads were discussed in Chapter 7. However, the accuracy of these methods is not known. The only way to assess the accuracy of different methodologies is to perform case studies and compare the results with count-based VMT estimates. Several traffic zones in different urban areas would be selected, and VMT estimation for the local roads done using different methods. A large sample of traffic counts would be obtained to develop reliable values of local road VMT to assess the accuracy of alternative procedures. The sample of traffic counts would be helpful for developing typical values of traffic on local roads with different types and densities of land use.
4. Sensitivity of corridor- and project-level air quality models (e.g., CAL3QHC and CALINE4) to different travel-related inputs. This project focused on traffic and emission factor input parameters and their effect on emission estimates from an areawide or networkwide perspective. However, for conformity analyses, the MPOs and state DOTs are becoming increasingly involved with project-level analysis. There is a need for examining air quality models, such as CAL3QHC and CALINE4, and their input requirements. The corridor-level air quality models need certain travel-related inputs that have not been examined by the current project. These should be identified and examined in depth.
5. Development of refined default values for selected parameters of MOBILE5a. Despite the availability of advanced methodologies for developing transportation inputs to air quality models, many MPOs cannot use these procedures because they lack trained personnel and sufficient funds. This serious problem is unlikely to be resolved soon. These MPOs have little choice but to use the aggregate default values incorporated in the MOBILE5a model such as those for VMT mix and operating mode fractions. A significant contribution can be made by performing research to develop a more detailed breakdown of these default values according to functional class of roadway, location, and time of day. For VMT mix, more field data have to be collected from various state and local agencies. For operating mode fractions, more analytical work has to be done with network and travel data from different urban areas. For travel speeds, actual speed runs should be made under varying traffic conditions along with analytical work with such tools as NETSIM.
6. Modifications of MOBILE5a's internal mechanisms for developing vehicle speed parameters. Several investigations can be undertaken with regard to the internal calibration of EPA's MOBILE5a model and uncertainty involving some of its parameters. These are discussed in detail in Chapter 6. However, any analysis involving the internal mechanism of MOBILE5a and any modifications for making MOBILE5a more user-friendly will require the consent and cooperation of the EPA.
7. Disaggregate application of MOBILE5a. The traditional procedure for emissions estimation is to use composite emissions rates in grams per mile representing the combined effect of various sources of emissions, which include startup emissions, running emissions, and several types of evaporative emissions. Innovative approaches for using MOBILE5a in a disaggregate manner, somewhat similar to the procedure used in California using EMFAC7F, exist. The Metropolitan Washington Council of Governments uses MOBILE5a in a disaggregate manner, as discussed in Chapter 2 under Trip-End Data. The difference in results of using a disaggregate approach from those of a traditional aggregate approach should be assessed in detail, along with the need for input data for the disaggregate approach. This is important because future emissions factor models are likely to be of disaggregate nature. This approach may be more applicable for certain types of analysis or cases than others, and these cases should be identified.
8. Improvements for travel forecasting models. Additional research is needed in order to understand completely the effects of travel demand modeling assumptions and procedures on emission estimates. These effects are particularly important in understanding the effect on project planning and the development of long-range plans that affect peak-period congestion. For example, application of feedback in the entire modeling process was not undertaken in the Baton Rouge case study because procedures for doing it have not been developed sufficiently well for easy research. This should be researched to determine if the effects of feedback iterations that successively improve the estimates of travel times in the network also increase estimated emissions. Second, the issue of the capacity

assumptions on links is of critical importance. Research is needed to determine the extent to which these assumptions affect the estimation of emissions, particularly with respect to obtaining appropriate estimates of levels of congestion. There is the potential to assign specific capacities to each link, rather than assigning capacities on the basis of functional class and area type. This is potentially feasible for networks that use geographic information systems and is being done by Oregon DOT for several of the smaller MPOs. Third, the effect of diurnal factoring when there is widespread traffic congestion on the road network and when a mode-choice model is used in the stepwise travel modeling process needs investigation.

APPENDIX A

SPEED CORRECTION FACTORS AND MONTE CARLO ANALYSES

The detailed methods employed to develop the MOBILE speed correction factors (SCFs) can be gleaned from the MOBILE4.1 (EPA, 1991), a publication by EEA (1991), and the MOBILE5a users manual (EPA, 1994a). Unfortunately, no single analytical document contains all of the detail necessary to reproduce the derivation of the SCFs contained in MOBILE5a. Information related to data screening criteria, specific regression equations and results, and conversion of analytical results into the weighted beta coefficients contained in the MOBILE5a code are lacking in all available references. Four different regression analysis approaches and various data screening methods were undertaken in the effort to replicate the results achieved by the algorithms contained in the MOBILE5a model. The regression functional form reported by the EPA (1991) coupled with the data screening criteria reported in a related work (EEA, 1991) best replicated MOBILE5a outputs when new SCF equations were generated through bootstrap analyses and incorporated into the MOBILE5a code.

SCF TEST DATA

EPA staff developed SCFs by testing 533 light-duty vehicles (317 pre-1986 carbureted or throttle body injected vehicles, 46 pre-1986 fuel-injected vehicles, 64 later-model carbureted or throttle body injected vehicles, and 106 later-model fuel-injected vehicles) on laboratory dynamometers under various chassis dynamometer cycles, including the FTP certification cycle (Guensler, 1993). Each emission testing cycle was characterized by a unique set of acceleration, deceleration, constant speed cruise, and idle activities in a fixed procedural pattern. (Table A-1 summarizes the test cycle characteristics.) Bag samples were collected from vehicle tailpipes for these test cycles, using the EPA constant volume sampling and analytical procedures outlined in the *Code of Federal Regulations*. The total emissions for each vehicle test were quantified, and the average emission rates per mile traveled (readily converted to grams per hour rates) were tabulated in the emissions database. Every vehicle was tested on the FTP and highway fuel economy test cycles, but no vehicle was tested on every cycle. Later, regression analysis was used to develop the relationship between average speeds and emission ratios (i.e., SCFs).

With the exception of the FTP Bag 1 and Bag 3 cycles, the testing cycles in Table A-1 were conducted with the vehicles already in a hot-stabilized mode. Because FTP Bag 1 and Bag 3 tests contained incremental emission components from incomplete combustion and poor catalytic converter control at engine start, these data were not used in developing hot-stabilized SCFs. Idle test results were also not employed in deriving SCFs.

In developing the SCFs, minimum non-zero test result values were established. Because ratios are used in estimating SCFs and because vehicles in practice emit more than zero grams of emissions per mile, the use of non-zero emission rates was necessary. All test results of zero emissions were assumed to fall halfway between zero and the minimum response threshold of the analytical equipment. Minimum test results for each pollutant were defined as: CO, 0.0250 grams per mile; HC, 0.0025 grams per mile; NO_x, 0.0025 grams per mile (EEA, 1991). The actual effect on regression results (mean square error and beta coefficients) arising from using minimum non-zero emission rates for the CARB modeling of SCFs was insignificant (Guensler, 1993). Thus, the effect on the SCFs is assumed to be insignificant for the EPA technology groups.

Logical reasons for classifying a case as an outlier would be data transcription errors during data collection or recording or clear indications that the data point was the obvious result of gross measurement error. Two data points were immediately eliminated from the database and from all regression analyses—one in the EPA CO database with a negative value and another in the EPA HC database with a missing character in the hundredths place (Guensler, 1993).

One might argue that extreme values should be treated as outliers; however, a case being "extreme" or "influential" is not sufficient evidence to characterize that data point as a statistical outlier. Rather, the case must be shown to be nonrepresentative of the rest of the remaining data. Once a case can been shown to be influential and abnormal, it can be considered an outlier and omitted from the data set. "Clearly, an outlying influential case should not be automatically discarded, because it may be entirely correct and simply represents an unlikely event" (Neter et al., 1990). Only through careful inspection and scrutiny of individual cases can such cases be considered outliers. Data should be excluded only if the data behave differently than the other data and if, for identifiable reasons, they belong in their own model (such as the idle emission data excluded by the CARB). If no explanation for an influential case can be derived, the data should be left in the data set (Neter et al., 1990).

Considerable analysis of the effect of potential outliers on the derivation of the CARB SCFs in EMFAC7F was under-

TABLE A-1 SCF test cycle characteristics

Cycle Name	Time (sec.)	Distance (miles)	Avg. Speed (mph)	Max. Speed (mph)	Std. Dev. Speed	% Cycle Idle	% Cycle Accel.	% Cycle Decel.	% Cycle Cruise
Low Speed Cycle #1	616	0.42	2.45	10.00	3.07	47.7	16.2	17.9	18.2
Low Speed Cycle #2	637	0.64	3.64	14.00	4.15	38.8	23.4	24.3	13.5
Low Speed Cycle #3	624	0.70	4.02	16.00	4.38	36.5	24.2	25.6	13.7
New York City Cycle	598	1.18	7.10	27.70	8.00	34.9	23.9	24.2	17.0
Speed Cycle 12	349	1.17	12.07	29.10	10.23	27.2	26.1	24.1	22.6
FTP Bag 1	505	3.59	25.58	56.67	18.23	19.6	21.0	20.4	39.0
FTP Bag 2	866	3.86	16.04	34.30	10.72	18.6	25.3	19.3	36.8
FTP Bag 3	505	3.59	25.58	56.67	18.23	19.6	21.0	20.4	39.0
Speed Cycle 36	996	9.92	35.85	57.00	18.88	6.5	19.0	16.0	58.5
Highway Fuel Economy Test	765	10.26	48.27	59.90	10.09	0.7	14.1	11.8	73.4
High Speed Cycle #1	474	5.93	45.07	53.30	9.67	1.1	13.3	9.9	75.7
High Speed Cycle #2	480	6.80	51.03	59.90	11.22	1.0	13.8	10.4	74.8
High Speed Cycle #3	486	7.80	57.77	67.40	13.03	1.0	14.2	10.9	73.9
High Speed Cycle #4	492	8.81	64.44	74.90	14.95	1.0	15.3	11.4	72.3

taken by Guensler (1993). The results of these analyses indicated that no data (other than the two data transcription errors noted) should be eliminated from SCF analysis. Removal of data from a data set in the manner apparently employed in developing SCFs is a significant analytical deficiency. Removal of data because "anomalous" test results were observed (a reflection of "engineering judgment") cannot be justified under statistical methods. However, because the analysts desired to reproduce the EPA results, several data points were removed.

The documentation contained in MOBILE5a documentation did not indicate which data were removed from the analyses as outliers. Previous analytical work by the CARB and EPA SCF analyses by EEA (1991) indicated that the data contained in Table A-2 were likely to have been screened from analyses and were removed from the research team's analyses as well. However, removing these data results in a reduction of noted variation in the SCF mean response curve and the slightly narrowed confidence interval bounds provide a false sense of security.

In MOBILE5a, SCFs for model year 1979 and later vehicles are derived for 13 vehicle technology groups, based on model year, fuel delivery technology, and emission control system characteristics (Table A-3).[1] The MOBILE5a SCF approach also employs separate SCF algorithms for normal-emitting and high-emitting vehicles within each technology group when sufficient high-emitting vehicle data were collected. The development of separate high-emitting SCFs increased the potential number of SCF models from 13 to 26.

Not all vehicles in the emission testing database or on the road were represented in the EPA's SCF vehicle technology groups. For example, there was one carbureted vehicle in the database that was open loop with a three-way catalyst. The EPA technology groups did not include a classification for this vehicle. Thus, this vehicle's data were not used in the analyses.

Within each technology group, when data allowed, the EPA developed a set of SCFs for high emitters and a second set for normal emitters. In data collection and analysis (and therefore application of the derived model), a vehicle is considered to be a high emitter for a pollutant when the FTP emissions are greater than 5 times the applicable certification standard (EPA, 1991). Table A-4 contains the certification-based criteria by pollutant and model year for vehicle qualification as a high emitter.

MOBILE5A REGRESSION FUNCTIONAL FORM

As mentioned earlier, four different regression analysis approaches and various data screening methods were undertaken in the effort to replicate the MOBILE5a SCFs. The regression functional form reported by the EPA (1991) best replicated MOBILE5a outputs. Linear regression is first employed to develop a relationship between average speed and gm/hour emission rates:

$$ER_{gph}=B_0 + B_1(S) + e$$

where:

ER_{gph} = Gm/hour emission rate (gm/mile emission rate times speed)
S = Avg. speed of cycle
B_0, B_1 = Least squares estimated regression coefficients
e = Disturbance term

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[1] The CARB developed SCF algorithms for four distinct vehicle technology groups while the EPA employed 26 vehicle technology groups (Guensler, 1993).

TABLE A-2 Vehicles identified as MOBILE5a "outliers" (and associated test results) based upon EEA (1991) criteria

Test	Vehicle	Transportation Group	Low Speed Cycle #1	Low Speed Cycle #2	Low Speed Cycle #3	New York City Cycle	Speed Cycle 12	FTP Bag 2	Speed Cycle 36	Highway Fuel Economy Test
CO	4299	6	-	-	-	4.2	2.3	2.3	4.6	15
	48	8	28.5	25	21.2	11	8	3.4	1.2	1
	56	8	78.8	38.9	30.5	22.3	8.6	5.8	1.4	1.1
	9025	9	25.6	12.5	24.7	0.2	0.1	0.025	0.025	0.025
	803	10	11.3	14.3	31.2	7.2	18.8	0.9	10.9	107.9
	25	12	38.5	43.4	42.5	53.4	5.4	2.4	30.6	0.4
HC										
	6146	3	10.24	11.87	11.63	4.44	2.1	0.31	0.18	0.18
	56	8	7.12	4.45	4.6	1.1	0.76	0.27	0.06	0.04
	73	10	11.98	8.21	7.24	1.34	2.07	0.47	0.19	0.09
	803	10	3.59	3.98	5.22	0.38	1.19	0.11	0.29	3.14

To predict grams per mile emissions for any average speed, the grams per hour relationships are applied and converted to grams per mile results by dividing all terms by average speed:

$$ER_{gpm} = B_0/S + B_1$$

where:

ER_{gph} = Predicted gm/mile emission rate
S = Average speed for which SCF is desired
B_0, B_1 = Least squares estimated regression coefficients derived in gph analysis

The SCF at any speed is predicted from the grams per hour regression results by taking the ratio of the predicted grams per mile emission rate at that speed and dividing by the predicted grams per mile emission rate at 19.6 mph (the average speed of the composite FTP).

Separate regression models were derived from data collected on low-speed cycles (Low Speed Cycle #1, Low Speed Cycle #2, Low Speed Cycle #3, New York City Cycle, Speed Cycle 12, and FTP Bag 2; 2.5 mph to 16 mph) and on medium speed cycles (FTP Bag 2, Speed Cycle 36, Highway Fuel Economy Test; 16 mph to 48.3 mph). The data sets overlap for the subset of data collected on FTP Bag 2. Although the data overlap for the single testing cycle that bridges the speed regimes (FTP Bag 2), because each regression model (and resulting curve) is based on separate data sets, a discontinuity results at the 16 mph value when the regression curves are plotted next to each other.

When the MOBILE5a model is run, the derived low-speed regression results are *applied* to average speeds ranging from

TABLE A-3 EPA vehicle technology group characteristics

EPA Technology Group	Model Year Group	Fuel Delivery Technology	Open or Closed Loop Technology	Catalyst Configuration
1	1981+	Carburated	Open Loop	Three-Way + Oxidation, or Oxidation
2	1981+	Carburated	Closed Loop	Three-Way
3	1981-82	Fuel Injected/ Throttle Body Injected	Closed Loop	Three-Way, or Three-Way + Oxidation
4	1981-82	Carburated	Closed Loop	Three-Way + Oxidation
5	1983+	Carburated	Closed Loop	Three-Way + Oxidation
6	1983-86	Throttle Body Injected	Closed Loop	Three-Way
7	1983-86	Throttle Body Injected	Closed Loop	Three-Way + Oxidation
8	1987+	Throttle Body Injected	Closed Loop	Three-Way
9	1987+	Throttle Body Injected	Closed Loop	Three-Way + Oxidation
10	1983-86	Fuel Injected	Closed Loop	Three-Way
11	1983-86	Fuel Injected	Closed Loop	Three-Way + Oxidation
12	1987+	Fuel Injected	Closed Loop	Three-Way
13	1987+	Fuel Injected	Closed Loop	Three-Way + Oxidation

Source: Energy and Environmental Analysis (1991). "Speed Correction Factors for the Updated Version of MOBILE4." Prepared for EPA, Contract No. 68-CO-0065. Ann Arbor, MI.

TABLE A-4 MOBILE5a high emitter criteria, FTP emission test result (gm/mile), data analysis, and model application

Pollutant	Model Year	FTP Emission Rate (gm/mile)
CO	Pre-1980	75.0
	1980	35.0
	1981+	17.0
HC	Pre-1980	7.5
	1980+	2.05
NOx	Pre-1977	15.5
	1977-1980	10.0
	1980+	5.0

Source: Environmental Protection Agency (1991). MOBILE4.1 Revisions and VMT Projection Guidance, Public Workshop Handouts. Office of Mobile Sources, Ann Arbor, MI.

2.5 mph to 20 mph and the derived medium-speed regression results are applied to average speeds ranging from 20 mph to 48 mph.[2]

The normalization process introduces bias into any predicted relationship between average speed and emission rate (or emissions ratio). SCF documentation (EEA, 1991) indicates that the discontinuity in low and medium SCF curves derived directly from low- and medium-speed data is addressed through a normalization process. The derived beta coefficients for each SCF equation are adjusted by dividing each by the predicted value from the mean response equation at 19.6 mph.[3] Undertaking such an analytical procedure biases the predicted outputs from the model, that is, a new "mean response curve" is generated that is significantly different from that mean response curve that minimized the sum of square errors in the regression analysis.

Mean response curves illustrate the modeled relationship between emissions and average speed currently employed in the MOBILE5a model. However, the probability distributions for these mean response curves would provide information on the variability of the mean response curve. The probability distributions of the mean SCF response can be examined by applying a bootstrap resampling technique to the original data sets for each technology group.

SCFS IN MOBILE5M, THE MONTE CARLO VERSION OF THE MOBILE5A MODEL

The MOBILE5a model uses the average speed input in the BIGSC3 subroutine to determine what SCF should be applied to a baseline exhaust emission rate to predict an emission rate for the desired average speed. The subroutine predicts the SCF from the regression-derived mean response algorithm embedded in the model. The probability distribution functions (PDFs) developed for the SCFs can be employed directly in the MOBILE5a model in lieu of the mean response curves embedded in the MOBILE5a subroutine BIGSC3.

The first step in developing a PDF algorithm for substitution into the MOBILE5a subroutine is to establish SCF matrixes (probability, by average speed, by SCF) for each technology group using the output from the bootstrap analyses. The bootstrap regression output matrix provides a PDF that is integrated into the MOBILE5m model. Each technology group matrix provides an SCF as a function of average speed and a probability from 0 to 1. Each time the MOBILE5m model is run, a random uniform number is generated, and the SCF is estimated from the matrix using the average speed input by the user and the random number generated internally. Hence, each time the model is run, a unique SCF is predicted from the PDF for a given average speed (given enough trials, the median of these predicted SCFs will equal the mean SCF derived from the test data and employed in the unmodified model).

Because a linear approximation does not, in general, give values of f(x) that have continuous first or higher derivatives (e.g., the resulting curve representing f(x) is not smooth), cubic spline functions are used to interpolate values that lie between probability and average speed values (i.e., in two dimensions) on the matrixes. Appendix E contains a description of the cubic spline function employed in the MOBILE5m model.

The beta coefficients employed in the BIGSC3 subroutine are contained in the BLOCK DATA BD01 subprogram of MOBILE5a. These beta coefficients are provided for each of the last 14 calendar years, rather than by technology group. Hence, EPA staff have already weighted the beta coefficients for each technology group by their fleet penetration rate to derive the compound beta coefficients for each calendar year. The weighting fractions employed by the EPA for each of the 26 technology groups (13 technology groups by high- and low-emitter classification) must be known if the PDF algorithms are to be substituted into the BIGSC3 subroutine.

Rather than call out to revised block data in the MOBILE5a FORTRAN code, a new PDF subroutine was developed that: (1) predicts the SCFs for each technology group using average speed input, a random uniform number, the SCF probability distributions, and the cubic spline function for interpolation; (2) weights the individual technology group SCFs by penetration of the technology into the model

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[2] The break point in MOBILE5a is based on the desire to center the speed regimes at 19.6 mph—the average speed of the composite FTP emission rates that are used as baseline exhaust emission rates in the model. This break point was deemed necessary by the EPA because the average fleet emission rates are adjusted at this speed for cold and hot operating mode fractions. This operating mode "adjustment" creates a different set of applicability problems that are not readily addressed through statistical reanalysis of the original data (Guensler, 1993).

[3] The application of the curves outside the range of values used to derive the function is problematic. In attempting to derive the EPA SCFs, the use of the 19.6 normalization point (so that the equation will predict a value of 1 when it is applied to average speeds of 19.6) created problems. Because 19.6 is outside of the data range, the bootstrap regressions often yielded negative or very small values at 19.6, resulting in large distortions to the resulting SCFs at other points during division. Furthermore, because no test cycles other than the FTP that employed hot- or cold-start operating modes, applying SCFs to "before" data that contain cold- and hot-start contributions is invalid (the potentially significant impact of driving mode on cold- and hot-start contributions is ignored).

TABLE A-5 Fleet penetration by EPA technology group

Model Year	Technology Group												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1981	0.281	0.23	0.089	0.399	0	0	0	0	0	0	0	0	0
1982	0.325	0.159	0.169	0.347	0	0	0	0	0	0	0	0	0
1983	0.244	0.022	0	0	0.464	0.115	0.068	0	0	0.086	0.002	0	0
1984	0.058	0.086	0	0	0.465	0.159	0.123	0	0	0.105	0.005	0	0
1985	0.076	0.129	0	0	0.279	0.058	0.15	0	0	0.292	0.016	0	0
1986	0.024	0.075	0	0	0.244	0.133	0.131	0	0	0.329	0.064	0	0
1987	0.018	0.064	0	0	0.184	0	0	0.217	0.146	0	0	0.347	0.024
1988	0	0.041	0	0	0.06	0	0	0.327	0.08	0	0	0.444	0.048
1989	0.003	0.072	0	0	0.053	0	0	0.239	0.036	0	0	0.546	0.051
1990	0.001	0.001	0	0	0.017	0	0	0.194	0.026	0	0	0.718	0.043
1991	0	0.001	0	0	0.002	0	0	0.189	0.012	0	0	0.774	0.021
1992	0	0.001	0	0	0.002	0	0	0.189	0.012	0	0	0.774	0.021
1993	0	0.001	0	0	0.002	0	0	0.189	0.012	0	0	0.774	0.021
1994+	0	0.001	0	0	0.002	0	0	0.189	0.012	0	0	0.774	0.021

year to estimate the SCF for the model year; and (3) replaces the BIGSAL SCF for that model year with the revised SCF for that model year. The SCF weighting is accomplished using the EPA-provided fleet penetration rates for the desired calendar year contained in Table A-5 (EPA, 1994b).

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Environmental Protection Agency (1994b). "Mobile 4.1 Technology Distributions for Gasoline Passenger Cars (TECHDATA.WK3)." Office of Mobile Sources, Ann Arbor, MI.

Guensler, R. (1993). *Vehicle Emission Rates and Average Vehicle Operating Speeds*. Unpublished dissertation, University of California, Davis, CA.

Neter, J., Wasserman, W., and Kutner, M. (1990). *Applied Linear Statistical Models*, Third Edition. Richard D. Irwin, Inc., Boston, MA.

APPENDIX B

THE MOBILE5m OUTPUT FILES FOR THE EIGHT FACILITY TYPE/ CONGESTION LEVEL RUNS

```
   Title:  "GPH NORMALIZED - Uncongested Arterial "

    Mean:  30.0
  StdDev:  0.000

    File:  MONTE403.PRN
   NRuns:  1000
    Seed:  7628383
  Run Id:  403
 =====================================================================
11          TITLE    -  NCHRP Monte Carlo Simulation
 MOBILE5a (26-Mar-93)
0VOC HC emission factors include evaporative HC emission factors.
0_____________________________________________________________________________
0Emission factors are as of Jan. 1st of the indicated calendar year.
0Cal. Year: 1995            Region: Low            Altitude:  500. Ft.
                       I/M Program: No        Ambient Temp:   75.0 / 75.0 / 75.0 F
                  Anti-tam. Program: No      Operating Mode:   20.6 / 27.3 / 20.6
                   Reformulated Gas: No
0Metropolis 1995
                       Minimum Temp: 60. (F)   Maximum Temp: 90. (F)
                       Period 1 RVP: 11.5      Period 2 RVP:   9.5 Period 2 Yr: 1992
0Veh. Type:  LDGV  LDGT1  LDGT2   LDGT   HDGV   LDDV   LDDT   HDDV    MC   All Veh
+           _____  _____  _____  _____  _____  _____  _____  _____  _____  _____
 Veh. Spd.: 30.0   30.0   30.0          30.0   30.0   30.0   30.0   30.0
   VMT Mix:  0.633  0.180  0.084         0.031  0.004  0.002  0.061  0.007
0Composite Emission Factors (Gm/Mile)
 VOC    HC:  1.99   2.47   3.32   2.74   6.15   0.54   0.79   1.84   4.60   2.32
 Exhst  HC:  1.19   1.58   2.20   1.78   2.66   0.54   0.79   1.84   1.48   1.43
 Evap.  HC:  0.42   0.54   0.67   0.58   2.67                        2.77   0.52
 Refuel HC:  0.00   0.00   0.00   0.00   0.00                               0.00
 Runing HC:  0.31   0.28   0.39   0.32   0.71                               0.30
 Rsting HC:  0.07   0.07   0.06   0.06   0.11                        0.34   0.07
 Exhst  CO: 15.78  19.26  26.12  21.45  57.74   1.11   1.30   7.93  13.13  18.00
 Exhst NOX:  1.74   1.99   2.48   2.15   6.06   1.45   1.68  12.81   1.03   2.64
_____________________________________________________________________________
 ========================================================================
   NUMBER OF SIMULATIONS:    1000
   NOTES: RANDOM SPEED CORRECTION FACTORS APPLIED TO
          LDGV EXHAUST VOC, HC, AND CO ONLY
          SPEEDS GREATER THAN 48 MPH USE STANDARD SCF.

   CLASS  POLTYP   LOW      2.5%      50%      97.5%     HIGH      MEAN     SDEV
   ------ ------ -------- -------- -------- -------- -------- -------- --------

   SPEED           30.000   30.000   30.000   30.000   30.000   30.000    0.000

   LDGV   VOC-HC    1.712    1.763    2.029    2.695   31.410    2.190    1.707
   LDGV   CO       12.264   13.120   16.373   25.552   56.851   17.206    3.998
   LDGV   NOx       1.738    1.738    1.738    1.738    1.738    1.738    0.000
   LDGV   EXH-HC    0.915    0.966    1.232    1.898   30.613    1.393    1.707

   LDGT1  VOC-HC    2.465    2.465    2.465    2.465    2.465    2.465    0.000
   LDGT1  CO       19.264   19.264   19.264   19.264   19.264   19.264    0.000
   LDGT1  NOx       1.991    1.991    1.991    1.991    1.991    1.991    0.000
   LDGT1  EXH-HC    1.579    1.579    1.579    1.579    1.579    1.579    0.000
   LDGT2  VOC-HC    3.319    3.319    3.319    3.319    3.319    3.319    0.000
   LDGT2  CO       26.116   26.116   26.116   26.116   26.116   26.116    0.000
   LDGT2  NOx       2.478    2.478    2.478    2.478    2.478    2.478    0.000
   LDGT2  EXH-HC    2.199    2.199    2.199    2.199    2.199    2.199    0.000
   MC     VOC-HC    4.599    4.599    4.599    4.599    4.599    4.599    0.000
   MC     CO       13.135   13.135   13.135   13.135   13.135   13.135    0.000
   MC     NOx       1.027    1.027    1.027    1.027    1.027    1.027    0.000
   MC     EXH-HC    1.482    1.482    1.482    1.482    1.482    1.482    0.000
```

```
  Title:   "GPH NORMALIZED - Congested Arterial    "

   Mean:   8.0
 StdDev:   0.000

   File:   MONTE404.PRN
  NRuns:   1000
   Seed:   7628383
 Run Id:   404
==============================================================
11         TITLE    -  NCHRP Monte Carlo Simulation
 MOBILE5a (26-Mar-93)
0VOC HC emission factors include evaporative HC emission factors.
0_______________________________________________________________________
0Emission factors are as of Jan. 1st of the indicated calendar year.
0Cal. Year: 1995           Region: Low          Altitude:  500. Ft.
                     I/M Program: No       Ambient Temp:   75.0 / 75.0 / 75.0 F
                 Anti-tam. Program: No     Operating Mode:   20.6 / 27.3 / 20.6
                  Reformulated Gas: No
0Metropolis 1995
                     Minimum Temp: 60. (F)   Maximum Temp: 90. (F)
                     Period 1 RVP: 11.5      Period 2 RVP:  9.5 Period 2 Yr: 1992
0Veh. Type:   LDGV  LDGT1  LDGT2   LDGT   HDGV   LDDV   LDDT   HDDV    MC   All Veh
+            _____  _____  _____  _____  _____  _____  _____  _____  _____  _____
 Veh. Spd.:   8.0    8.0    8.0           8.0    8.0    8.0    8.0    8.0
   VMT Mix:  0.633  0.180  0.084         0.031  0.004  0.002  0.061  0.007
0Composite Emission Factors (Gm/Mile)
 VOC    HC:  5.24   6.39   8.85   7.17  16.77   1.25   1.84   4.27   7.31   6.04
 Exhst  HC:  3.42   4.36   6.35   4.99  11.25   1.25   1.84   4.27   4.20   4.12
 Evap.  HC:  0.42   0.54   0.67   0.58   2.67                         2.77   0.52
 Refuel HC:  0.00   0.00   0.00   0.00   0.00                                0.00
 Runing HC:  1.34   1.42   1.77   1.53   2.74                                1.34
 Rsting HC:  0.07   0.07   0.06   0.06   0.11                         0.34   0.07
 Exhst  CO: 46.32  56.47  82.94  64.90 198.81   3.61   4.21  25.69  52.85  54.50
 Exhst NOX:  1.83   2.02   2.47   2.16   4.99   2.30   2.67  20.35   0.78   3.13
 ______________________________________________________________________________
 ==============================================================================
  NUMBER OF SIMULATIONS:   1000
  NOTES: RANDOM SPEED CORRECTION FACTORS APPLIED TO
         LDGV EXHAUST VOC, HC, AND CO ONLY
         SPEEDS GREATER THAN 48 MPH USE STANDARD SCF.

  CLASS  POLTYP    LOW      2.5%      50%      97.5%     HIGH      MEAN      SDEV
  ------ ------ -------- -------- -------- -------- -------- -------- --------

  SPEED            8.000    8.000    8.000    8.000    8.000    8.000    0.000

  LDGV   VOC-HC    3.943    4.472    5.764   14.139  522.120    8.759   30.321
  LDGV   CO       21.872   23.663   40.367  340.668 ********  234.940 2261.039
  LDGV   NOx       1.827    1.827    1.827    1.827    1.827    1.827    0.000
  LDGV   EXH-HC    2.119    2.648    3.940   12.315  520.296    6.935   30.321

  LDGT1  VOC-HC    6.385    6.385    6.385    6.385    6.385    6.385    0.000
  LDGT1  CO       56.473   56.473   56.473   56.473   56.473   56.473    0.000
  LDGT1  NOx       2.018    2.018    2.018    2.018    2.018    2.018    0.000
  LDGT1  EXH-HC    4.361    4.361    4.361    4.361    4.361    4.361    0.000
  LDGT2  VOC-HC    8.852    8.852    8.852    8.852    8.852    8.852    0.000
  LDGT2  CO       82.941   82.941   82.941   82.941   82.941   82.940    0.000
  LDGT2  NOx       2.469    2.469    2.469    2.469    2.469    2.469    0.000
  LDGT2  EXH-HC    6.345    6.345    6.345    6.345    6.345    6.345    0.000
  MC     VOC-HC    7.312    7.312    7.312    7.312    7.312    7.312    0.000
  MC     CO       52.854   52.854   52.854   52.854   52.854   52.854    0.001
  MC     NOx       0.785    0.785    0.785    0.785    0.785    0.785    0.000
  MC     EXH-HC    4.196    4.196    4.196    4.196    4.196    4.196    0.000
```

```
   Title:   "GPH NORMALIZED - Uncongested Freeway  "

    Mean:   55.0
  StdDev:   0.000

    File:   MONTE401.PRN
   NRuns:   1000
    Seed:   7628383
  Run Id:   401
 =======================================================================
11          TITLE     -  NCHRP Monte Carlo Simulation
 MOBILE5a (26-Mar-93)
OVOC HC emission factors include evaporative HC emission factors.
0_________________________________________________________________________________
OEmission factors are as of Jan. 1st of the indicated calendar year.
OCal. Year: 1995            Region: Low          Altitude:  500. Ft.
                       I/M Program: No       Ambient Temp:   75.0 / 75.0 / 75.0 F
                 Anti-tam. Program: No     Operating Mode:   20.6 / 27.3 / 20.6
                  Reformulated Gas: No
OMetropolis 1995
                      Minimum Temp: 60. (F)  Maximum Temp: 90. (F)
                      Period 1 RVP: 11.5     Period 2 RVP:  9.5 Period 2 Yr: 1992
OVeh. Type:   LDGV  LDGT1  LDGT2   LDGT   HDGV   LDDV   LDDT   HDDV    MC   All Veh
+            ______ ______ ______ ______ ______ ______ ______ ______ ______ ______
 Veh. Spd.: 55.0   55.0   55.0          55.0   55.0   55.0   55.0   55.0
   VMT Mix:  0.633  0.180  0.084         0.031  0.004  0.002  0.061  0.007
OComposite Emission Factors (Gm/Mile)
 VOC    HC:  1.42   1.87   2.49   2.07   4.46   0.35   0.51   1.18   4.23   1.69
 Exhst  HC:  0.83   1.15   1.59   1.29   1.38   0.35   0.51   1.18   1.12   0.99
 Evap.  HC:  0.42   0.54   0.67   0.58   2.67                        2.77   0.52
 Refuel HC:  0.00   0.00   0.00   0.00   0.00                               0.00
 Runing HC:  0.11   0.12   0.17   0.13   0.31                               0.11
 Rsting HC:  0.07   0.07   0.06   0.06   0.11                        0.34   0.07
 Exhst  CO: 11.06  13.96  19.32  15.67  51.60   0.85   1.00   6.08   8.06  13.15
 Exhst NOX:  2.30   2.69   3.41   2.92   7.29   1.97   2.29  17.45   1.46   3.53
 _________________________________________________________________________________
 ============================================================================
  NUMBER OF SIMULATIONS:   1000
  NOTES: RANDOM SPEED CORRECTION FACTORS APPLIED TO
         LDGV EXHAUST VOC, HC, AND CO ONLY
         SPEEDS GREATER THAN 48 MPH USE STANDARD SCF.

  CLASS  POLTYP   LOW      2.5%      50%     97.5%     HIGH      MEAN      SDEV
  ------ ------ -------- -------- -------- -------- -------- -------- --------

  SPEED          55.000   55.000   55.000   55.000   55.000   55.000    0.000

  LDGV   VOC-HC   1.425    1.425    1.425    1.425    1.425    1.425    0.000
  LDGV   CO      11.060   11.060   11.060   11.060   11.060   11.060    0.000
  LDGV   NOx      2.304    2.304    2.304    2.304    2.304    2.304    0.000
  LDGV   EXH-HC   0.831    0.831    0.831    0.831    0.831    0.831    0.000

  LDGT1  VOC-HC   1.867    1.867    1.867    1.867    1.867    1.867    0.000
  LDGT1  CO      13.965   13.965   13.965   13.965   13.965   13.965    0.000
  LDGT1  NOx      2.685    2.685    2.685    2.685    2.685    2.685    0.000
  LDGT1  EXH-HC   1.145    1.145    1.145    1.145    1.145    1.145    0.000
  LDGT2  VOC-HC   2.493    2.493    2.493    2.493    2.493    2.493    0.000
  LDGT2  CO      19.324   19.324   19.324   19.324   19.324   19.324    0.000
  LDGT2  NOx      3.409    3.409    3.409    3.409    3.409    3.409    0.000
  LDGT2  EXH-HC   1.592    1.592    1.592    1.592    1.592    1.592    0.000
  MC     VOC-HC   4.232    4.232    4.232    4.232    4.232    4.232    0.000
  MC     CO       8.064    8.064    8.064    8.064    8.064    8.064    0.000
  MC     NOx      1.458    1.458    1.458    1.458    1.458    1.458    0.000
  MC     EXH-HC   1.115    1.115    1.115    1.115    1.115    1.115    0.000
```

```
  Title:   "GPH NORMALIZED - Congested Freeway     "

   Mean:   16.0
 StdDev:   0.000

   File:   MONTE402.PRN
  NRuns:   1000
   Seed:   7628383
 Run Id:   402
=============================================================================
11          TITLE    -  NCHRP Monte Carlo Simulation
 MOBILE5a (26-Mar-93)
0VOC HC emission factors include evaporative HC emission factors.
0
0Emission factors are as of Jan. 1st of the indicated calendar year.
0Cal. Year: 1995              Region: Low          Altitude:  500. Ft.
                         I/M Program: No        Ambient Temp:   75.0 / 75.0 / 75.0 F
                   Anti-tam. Program: No      Operating Mode:   20.6 / 27.3 / 20.6
                    Reformulated Gas: No
0Metropolis 1995
                        Minimum Temp: 60. (F)   Maximum Temp: 90. (F)
                        Period 1 RVP: 11.5      Period 2 RVP:   9.5 Period 2 Yr: 1992
0Veh. Type:  LDGV  LDGT1  LDGT2   LDGT   HDGV   LDDV   LDDT   HDDV    MC   All Veh
+
 Veh. Spd.: 16.0   16.0   16.0          16.0   16.0   16.0   16.0   16.0
   VMT Mix:  0.633  0.180  0.084         0.031  0.004  0.002  0.061  0.007
0Composite Emission Factors (Gm/Mile)
 VOC    HC:  3.13   3.79   5.11   4.21  10.22   0.88   1.29   2.99   5.43   3.63
 Exhst  HC:  1.97   2.52   3.54   2.85   6.07   0.88   1.29   2.99   2.32   2.39
 Evap.  HC:  0.42   0.54   0.67   0.58   2.67                         2.77   0.52
 Refuel HC:  0.00   0.00   0.00   0.00   0.00                                0.00
 Runing HC:  0.67   0.66   0.84   0.72   1.37                                0.66
 Rsting HC:  0.07   0.07   0.06   0.06   0.11                         0.34   0.07
 Exhst  CO: 26.20  31.35  42.77  34.99 112.12   2.12   2.48  15.13  25.16  30.37
 Exhst NOX:  1.68   1.88   2.33   2.03   5.38   1.79   2.09  15.88   0.80   2.74

 ============================================================================
  NUMBER OF SIMULATIONS:   1000
  NOTES: RANDOM SPEED CORRECTION FACTORS APPLIED TO
         LDGV EXHAUST VOC, HC, AND CO ONLY
         SPEEDS GREATER THAN 48 MPH USE STANDARD SCF.

  CLASS  POLTYP    LOW      2.5%      50%      97.5%    HIGH      MEAN     SDEV
  ------ ------ -------- -------- -------- -------- -------- -------- --------

  SPEED           16.000   16.000   16.000   16.000   16.000   16.000    0.000

  LDGV   VOC-HC    2.702    2.969    3.208    4.507   83.332    3.663    4.706
  LDGV   CO       18.149   18.842   24.614   71.872 5946.510   54.858  350.907
  LDGV   NOx       1.682    1.682    1.682    1.682    1.682    1.682    0.000
  LDGV   EXH-HC    1.544    1.811    2.050    3.349   82.174    2.505    4.706

  LDGT1  VOC-HC    3.787    3.787    3.787    3.787    3.787    3.787    0.000
  LDGT1  CO       31.354   31.354   31.354   31.354   31.354   31.354    0.000
  LDGT1  NOx       1.884    1.884    1.884    1.884    1.884    1.884    0.000
  LDGT1  EXH-HC    2.523    2.523    2.523    2.523    2.523    2.523    0.000
  LDGT2  VOC-HC    5.114    5.114    5.114    5.114    5.114    5.114    0.000
  LDGT2  CO       42.773   42.773   42.773   42.773   42.773   42.773    0.000
  LDGT2  NOx       2.331    2.331    2.331    2.331    2.331    2.331    0.000
  LDGT2  EXH-HC    3.540    3.540    3.540    3.540    3.540    3.540    0.000
  MC     VOC-HC    5.434    5.434    5.434    5.434    5.434    5.434    0.000
  MC     CO       25.160   25.160   25.160   25.160   25.160   25.160    0.000
  MC     NOx       0.797    0.797    0.797    0.797    0.797    0.797    0.000
  MC     EXH-HC    2.317    2.317    2.317    2.317    2.317    2.317    0.000
```

```
   Title:   "GPH NORMALIZED - Uncongested Arterial "

    Mean:   30.0
  StdDev:   0.225

    File:   MONTE407.PRN
   NRuns:   1000
    Seed:   7628383
  Run Id:   407
===========================================================================
11           TITLE    -  NCHRP Monte Carlo Simulation
 MOBILE5a (26-Mar-93)
OVOC HC emission factors include evaporative HC emission factors.
0
-----------------------------------------------------------------------------------
OEmission factors are as of Jan. 1st of the indicated calendar year.
OCal. Year: 1995             Region: Low          Altitude:  500. Ft.
                        I/M Program: No        Ambient Temp:   75.0 / 75.0 / 75.0 F
                 Anti-tam. Program: No      Operating Mode:   20.6 / 27.3 / 20.6
                  Reformulated Gas: No
OMetropolis 1995
                      Minimum Temp: 60. (F)  Maximum Temp: 90. (F)
                      Period 1 RVP: 11.5     Period 2 RVP:  9.5 Period 2 Yr: 1992
OVeh. Type:  LDGV  LDGT1  LDGT2   LDGT    HDGV   LDDV   LDDT   HDDV   MC    All Veh
+            -----  -----  -----  ------  -----  -----  -----  -----  -----  ------
 Veh. Spd.: 30.0   30.0   30.0            30.0   30.0   30.0   30.0   30.0
  VMT Mix:  0.633  0.180  0.084           0.031  0.004  0.002  0.061  0.007
OComposite Emission Factors (Gm/Mile)
 VOC    HC:  1.99   2.47   3.32   2.74    6.15   0.54   0.79   1.84   4.60   2.32
 Exhst  HC:  1.19   1.58   2.20   1.78    2.66   0.54   0.79   1.84   1.48   1.43
 Evap.  HC:  0.42   0.54   0.67   0.58    2.67                         2.77   0.52
 Refuel HC:  0.00   0.00   0.00   0.00    0.00                                0.00
 Runing HC:  0.31   0.28   0.39   0.32    0.71                                0.30
 Rsting HC:  0.07   0.07   0.06   0.06    0.11                         0.34   0.07
 Exhst  CO: 15.78  19.26  26.12  21.45   57.74   1.11   1.30   7.93  13.13  18.00
 Exhst NOX:  1.74   1.99   2.48   2.15    6.06   1.45   1.68  12.81   1.03   2.64

-----------------------------------------------------------------------------------
===============================================================================
   NUMBER OF SIMULATIONS:   1000
   NOTES: RANDOM SPEED CORRECTION FACTORS APPLIED TO
          LDGV EXHAUST VOC, HC, AND CO ONLY
          SPEEDS GREATER THAN 48 MPH USE STANDARD SCF.

   CLASS  POLTYP    LOW      2.5%      50%     97.5%    HIGH     MEAN     SDEV
   ------ ------ -------- -------- -------- -------- -------- -------- --------

   SPEED          29.372   29.574   30.012   30.440   30.898   30.007    0.220

   LDGV   VOC-HC   1.701    1.775    2.029    2.694   31.579    2.190    1.701
   LDGV   CO      12.141   13.157   16.381   25.491   57.052   17.208    3.994
   LDGV   NOx      1.735    1.736    1.738    1.740    1.743    1.738    0.001
   LDGV   EXH-HC   0.906    0.975    1.232    1.894   30.783    1.393    1.701

   LDGT1  VOC-HC   2.421    2.445    2.465    2.486    2.496    2.465    0.011
   LDGT1  CO      18.819   19.063   19.264   19.470   19.575   19.261    0.112
   LDGT1  NOx      1.986    1.988    1.991    1.995    1.999    1.991    0.002
   LDGT1  EXH-HC   1.543    1.563    1.579    1.595    1.604    1.579    0.009
   LDGT2  VOC-HC   3.258    3.291    3.319    3.347    3.362    3.319    0.015
   LDGT2  CO      25.559   25.864   26.116   26.374   26.505   26.113    0.141
   LDGT2  NOx      2.471    2.473    2.478    2.482    2.487    2.478    0.002
   LDGT2  EXH-HC   2.150    2.177    2.199    2.222    2.234    2.199    0.012
   MC     VOC-HC   4.566    4.584    4.599    4.614    4.622    4.599    0.008
   MC     CO      12.687   12.933   13.135   13.341   13.446   13.132    0.113
   MC     NOx      1.018    1.021    1.027    1.033    1.040    1.027    0.003
   MC     EXH-HC   1.449    1.468    1.482    1.498    1.505    1.482    0.008
```

```
  Title:   "GPH NORMALIZED - Congested Arterial   "

   Mean:   8.0
 StdDev:   0.400

   File:   MONTE408.PRN
  NRuns:   1000
   Seed:   7628383
 Run Id:   408
=====================================================================
11          TITLE    -  NCHRP Monte Carlo Simulation
 MOBILE5a (26-Mar-93)
0VOC HC emission factors include evaporative HC emission factors.
0____________________________________________________________________________
0Emission factors are as of Jan. 1st of the indicated calendar year.
0Cal. Year: 1995              Region: Low            Altitude:   500. Ft.
                         I/M Program: No         Ambient Temp:    75.0 / 75.0 / 75.0 F
                   Anti-tam. Program: No       Operating Mode:    20.6 / 27.3 / 20.6
                    Reformulated Gas: No
0Metropolis 1995
                        Minimum Temp: 60. (F)    Maximum Temp: 90. (F)
                        Period 1 RVP: 11.5       Period 2 RVP:   9.5 Period 2 Yr: 1992
0Veh. Type:   LDGV   LDGT1   LDGT2    LDGT    HDGV    LDDV    LDDT    HDDV     MC    All Veh
+            _____  ______  ______  ______  ______  ______  ______  ______  ______  ______
 Veh. Spd.:   8.0    8.0     8.0             8.0     8.0     8.0     8.0     8.0
   VMT Mix:  0.633  0.180   0.084           0.031   0.004   0.002   0.061   0.007
0Composite Emission Factors (Gm/Mile)
 VOC    HC:  5.24    6.39    8.85    7.17   16.77    1.25    1.84    4.27    7.31    6.04
 Exhst  HC:  3.42    4.36    6.35    4.99   11.25    1.25    1.84    4.27    4.20    4.12
 Evap.  HC:  0.42    0.54    0.67    0.58    2.67                            2.77    0.52
 Refuel HC:  0.00    0.00    0.00    0.00    0.00                                    0.00
 Runing HC:  1.34    1.42    1.77    1.53    2.74                                    1.34
 Rsting HC:  0.07    0.07    0.06    0.06    0.11                            0.34    0.07
 Exhst  CO: 46.32   56.47   82.94   64.90  198.81    3.61    4.21   25.69   52.85   54.50
 Exhst NOX:  1.83    2.02    2.47    2.16    4.99    2.30    2.67   20.35    0.78    3.13
 ____________________________________________________________________________
 =========================================================================
  NUMBER OF SIMULATIONS:    1000
  NOTES: RANDOM SPEED CORRECTION FACTORS APPLIED TO
         LDGV EXHAUST VOC, HC, AND CO ONLY
         SPEEDS GREATER THAN 48 MPH USE STANDARD SCF.

  CLASS  POLTYP    LOW      2.5%      50%      97.5%    HIGH      MEAN     SDEV
  ------ ------ -------- -------- -------- -------- -------- -------- --------

  SPEED             6.883    7.242    8.021    8.783    9.596    8.012    0.392

  LDGV   VOC-HC     3.840    4.432    5.813   14.650  595.197    8.827   31.131
  LDGV   CO        21.492   23.612   40.743  340.963 ********  237.982 2319.041
  LDGV   NOx        1.779    1.801    1.827    1.859    1.873    1.827    0.014
  LDGV   EXH-HC     2.066    2.637    3.981   12.839  593.305    7.003   31.130

  LDGT1  VOC-HC     5.561    5.938    6.385    6.923    7.192    6.388    0.241
  LDGT1  CO        47.986   51.835   56.473   62.158   64.631   56.509    2.522
  LDGT1  NOx        1.969    1.991    2.018    2.051    2.066    2.018    0.015
  LDGT1  EXH-HC     3.743    4.024    4.361    4.772    4.951    4.363    0.183
  LDGT2  VOC-HC     7.634    8.190    8.852    9.654   10.051    8.857    0.359
  LDGT2  CO        69.320   75.498   82.941   92.051   96.009   82.998    4.045
  LDGT2  NOx        2.418    2.440    2.469    2.504    2.519    2.469    0.015
  LDGT2  EXH-HC     5.397    5.827    6.345    6.978    7.253    6.349    0.281
  MC     VOC-HC     6.670    6.963    7.312    7.734    7.914    7.314    0.189
  MC     CO        43.244   47.598   52.854   59.263   62.029   52.891    2.851
  MC     NOx        0.769    0.776    0.785    0.797    0.803    0.785    0.005
  MC     EXH-HC     3.554    3.846    4.196    4.617    4.798    4.197    0.189
```

```
  Title:  "GPH NORMALIZED - Uncongested Freeway  "

   Mean:  55.0
 StdDev:  0.550

   File:  MONTE405.PRN
  NRuns:  1000
   Seed:  7628383
 Run Id:  405
==============================================================================
11          TITLE   -  NCHRP Monte Carlo Simulation
 MOBILE5a (26-Mar-93)
OVOC HC emission factors include evaporative HC emission factors.
0________________________________________________________________________________
OEmission factors are as of Jan. 1st of the indicated calendar year.
OCal. Year: 1995            Region: Low        Altitude:  500. Ft.
                       I/M Program: No       Ambient Temp:   75.0 / 75.0 / 75.0 F
                 Anti-tam. Program: No     Operating Mode:   20.6 / 27.3 / 20.6
                  Reformulated Gas: No
OMetropolis 1995
                        Minimum Temp: 60. (F)   Maximum Temp: 90. (F)
                        Period 1 RVP: 11.5      Period 2 RVP:  9.5 Period 2 Yr: 1992
OVeh. Type:  LDGV  LDGT1  LDGT2   LDGT   HDGV   LDDV   LDDT   HDDV   MC   All Veh
+           ______ ______ ______ ______ ______ ______ ______ ______ ______ ______
 Veh. Spd.: 55.0   55.0   55.0           55.0   55.0   55.0   55.0   55.0
   VMT Mix:  0.633  0.180  0.084          0.031  0.004  0.002  0.061  0.007
OComposite Emission Factors (Gm/Mile)
 VOC    HC:  1.42   1.87   2.49   2.07   4.46   0.35   0.51   1.18   4.23   1.69
 Exhst  HC:  0.83   1.15   1.59   1.29   1.38   0.35   0.51   1.18   1.12   0.99
 Evap.  HC:  0.42   0.54   0.67   0.58   2.67                        2.77   0.52
 Refuel HC:  0.00   0.00   0.00   0.00   0.00                               0.00
 Runing HC:  0.11   0.12   0.17   0.13   0.31                               0.11
 Rsting HC:  0.07   0.07   0.06   0.06   0.11                        0.34   0.07
 Exhst  CO: 11.06  13.96  19.32  15.67  51.60   0.85   1.00   6.08   8.06  13.15
 Exhst NOX:  2.30   2.69   3.41   2.92   7.29   1.97   2.29  17.45   1.46   3.53
________________________________________________________________________________
  ===============================================================================
  NUMBER OF SIMULATIONS:   1000
  NOTES: RANDOM SPEED CORRECTION FACTORS APPLIED TO
         LDGV EXHAUST VOC, HC, AND CO ONLY
         SPEEDS GREATER THAN 48 MPH USE STANDARD SCF.

  CLASS   POLTYP    LOW      2.5%      50%      97.5%     HIGH     MEAN      SDEV
  ------  ------ -------- -------- -------- -------- -------- -------- --------

  SPEED            53.464   53.958   55.029   56.076   57.194   55.017    0.538

  LDGV    VOC-HC    1.425    1.425    1.429    1.469    1.514    1.434    0.013
  LDGV    CO       11.060   11.060   11.060   12.892   14.724   11.432    0.536
  LDGV    NOx       2.200    2.235    2.304    2.381    2.458    2.306    0.038
  LDGV    EXH-HC    0.831    0.831    0.831    0.879    0.928    0.841    0.014

  LDGT1   VOC-HC    1.867    1.867    1.871    1.937    2.009    1.882    0.020
  LDGT1   CO       13.965   13.965   13.965   16.773   19.581   14.534    0.822
  LDGT1   NOx       2.559    2.601    2.685    2.778    2.871    2.687    0.046
  LDGT1   EXH-HC    1.145    1.145    1.145    1.220    1.295    1.160    0.022
  LDGT2   VOC-HC    2.493    2.493    2.500    2.602    2.711    2.516    0.031
  LDGT2   CO       19.324   19.324   19.324   23.562   27.800   20.184    1.241
  LDGT2   NOx       3.241    3.297    3.409    3.532    3.655    3.411    0.060
  LDGT2   EXH-HC    1.592    1.592    1.592    1.707    1.823    1.615    0.034
  MC      VOC-HC    4.232    4.232    4.232    4.319    4.407    4.250    0.026
  MC      CO        8.064    8.064    8.064   10.201   12.337    8.498    0.625
  MC      NOx       1.400    1.419    1.458    1.500    1.543    1.458    0.021
  MC      EXH-HC    1.115    1.115    1.115    1.203    1.290    1.133    0.026
```

```
  Title:  "GPH NORMALIZED - Congested Freeway     "

   Mean:  16.0
 StdDev:  1.600

   File:  MONTE406.PRN
  NRuns:  1000
   Seed:  7628383
 Run Id:  406
==================================================================
11          TITLE    -  NCHRP Monte Carlo Simulation
 MOBILE5a (26-Mar-93)
0VOC HC emission factors include evaporative HC emission factors.
0
0Emission factors are as of Jan. 1st of the indicated calendar year.
0Cal. Year: 1995            Region: Low           Altitude:  500. Ft.
                       I/M Program: No        Ambient Temp:   75.0 / 75.0 / 75.0 F
                  Anti-tam. Program: No      Operating Mode:   20.6 / 27.3 / 20.6
                   Reformulated Gas: No
0Metropolis 1995
                       Minimum Temp: 60. (F)   Maximum Temp: 90. (F)
                       Period 1 RVP: 11.5      Period 2 RVP:  9.5 Period 2 Yr: 1992
0Veh. Type:  LDGV  LDGT1  LDGT2   LDGT   HDGV   LDDV   LDDT   HDDV   MC    All Veh
+
 Veh. Spd.: 16.0   16.0   16.0           16.0   16.0   16.0   16.0   16.0
   VMT Mix:  0.633  0.180  0.084          0.031  0.004  0.002  0.061  0.007
0Composite Emission Factors (Gm/Mile)
 VOC    HC:  3.13   3.79   5.11   4.21  10.22   0.88   1.29   2.99   5.43    3.63
 Exhst  HC:  1.97   2.52   3.54   2.85   6.07   0.88   1.29   2.99   2.32    2.39
 Evap.  HC:  0.42   0.54   0.67   0.58   2.67                         2.77    0.52
 Refuel HC:  0.00   0.00   0.00   0.00   0.00                                 0.00
 Runing HC:  0.67   0.66   0.84   0.72   1.37                                 0.66
 Rsting HC:  0.07   0.07   0.06   0.06   0.11                         0.34    0.07
 Exhst  CO: 26.20  31.35  42.77  34.99 112.12   2.12   2.48  15.13  25.16   30.37
 Exhst NOX:  1.68   1.88   2.33   2.03   5.38   1.79   2.09  15.88   0.80    2.74

==================================================================
  NUMBER OF SIMULATIONS:    1000
  NOTES: RANDOM SPEED CORRECTION FACTORS APPLIED TO
         LDGV EXHAUST VOC, HC, AND CO ONLY
         SPEEDS GREATER THAN 48 MPH USE STANDARD SCF.

  CLASS  POLTYP    LOW      2.5%      50%      97.5%     HIGH      MEAN      SDEV
  ------ ------ -------- -------- -------- -------- -------- -------- --------

  SPEED           11.532   12.969   16.086   19.131   22.384   16.049    1.566

  LDGV   VOC-HC    2.396    2.651    3.219    5.123  142.910    3.708    5.646
  LDGV   CO       17.827   18.842   24.873   81.754 ********   56.896  417.747
  LDGV   NOx       1.658    1.661    1.682    1.715    1.738    1.684    0.014
  LDGV   EXH-HC    1.452    1.678    2.055    3.882  141.632    2.549    5.639

  LDGT1  VOC-HC    2.963    3.289    3.769    4.432    4.857    3.800    0.292
  LDGT1  CO       24.286   27.344   31.201   37.049   41.049   31.520    2.484
  LDGT1  NOx       1.869    1.872    1.884    1.910    1.930    1.886    0.010
  LDGT1  EXH-HC    1.981    2.227    2.512    2.942    3.236    2.535    0.183
  LDGT2  VOC-HC    4.007    4.451    5.089    6.008    6.613    5.136    0.398
  LDGT2  CO       32.466   36.508   42.532   51.807   58.198   43.052    3.912
  LDGT2  NOx       2.315    2.318    2.330    2.357    2.378    2.333    0.010
  LDGT2  EXH-HC    2.756    3.098    3.523    4.173    4.620    3.559    0.275
  MC     VOC-HC    4.945    5.157    5.423    5.845    6.144    5.447    0.177
  MC     CO       18.028   21.118   25.003   31.140   35.495   25.356    2.569
  MC     NOx       0.765    0.769    0.798    0.842    0.899    0.800    0.019
  MC     EXH-HC    1.828    2.040    2.306    2.729    3.027    2.331    0.177
```

APPENDIX C

THE INPUT FILE EMPLOYED IN MOBILE5m COMPARISONS

```
1          PROMPT  -  No operator interface
1          TITLE   -  NCHRP Monte Carlo Simulation
1          TAMFLG  -  Uses embedded vehicle tampering rates
1          SPDFLG  -  Uses average speed from your scenario record
1          VMFLAG  -  Uses embedded % VMT by vehicle class (composite ER)
1          MYMRFG  -  Uses embedded MY mileage accrual rates
1          NEWFLG  -  Uses embedded BEFs by model year
1          IMFLAG  -  Excludes I&M benefits
1          ALHFLG  -  Excludes correction factors (other than speed and temp)
1          ATPFLG  -  Excludes anti-tampering benefits
5          RLFLAG  -  Excludes refueling emissions from g/mi emission rates
1          LOCFLG  -  Reads local area parameters in records below
2          TEMFLG  -  Ambient temperature is used for HC (except diurnal)
4          OUTFMT  -  Output format is 80 column
4          PRTFLG  -  Reports emission rates for HC, CO, and NOx
2          IDLFLG  -  Reports idle emission rates
3          NMHFLG  -  Reports only VOC component of HC emissions
2          HCFLAG  -  Prints HC emission components (including evaporatives)
1 95 19.6 75.0 20.6 27.3 20.6                  Altitude, year, speed, ambient
      temp, % non-cat VMT in Cold Start, % cat VMT in Hot Start, %cat VMT in Cold
      Start
Metropolis 1995     60.  90. 11.5  9.5 92      Scenario Name, min temp, max temp,
      Base RVP, Controlled RVP, Year RVP rule adopted
00000000000000000000000000000000000000000000000000000000000000000000000000000000
```

APPENDIX D

RECOMMENDATIONS FOR FOLLOW-UP MOBILE5M UNCERTAINTY ANALYSES

1. Convert MOBILE5m source code from OS2 to DOS, develop a smooth operator interface, and provide copies to interested parties.
2. Develop a front end for MOBILE5m, to make the structure user-friendly. Add a graphical user interface that provides for ease of input and check boxes to turn on and off input variable and internal algorithm variation.
3. Integrate an internal capability that will allow MOBILE5m to be run only the number of times necessary to ensure that variation has stabilized (i.e., ensure standard error stability).
4. Develop bootstrap PDFs for NO_x and incorporate Monte Carlo capabilities for these distributions in MOBILE5m (polynomial functional form requires additional staff programming efforts).
5. Develop bootstrap PDFs for CO, HC, and NO_x at high speeds and incorporate Monte Carlo capabilities for these distributions in MOBILE5m (polynomial functional form requires additional staff programming efforts). Because the CARB never reported the CATA (catalyst configuration) for each of these vehicles, either new technology groups must be employed or the laboratory notes must be examined to identify appropriate EPA technology groups.
6. Revisit the temperature correction factors employed in the MOBILE5a model. Develop mean response PDFs based on original data employed to generate temperature correction factors. Incorporate Monte Carlo capabilities for temperature correction factor distributions in MOBILE5m.
7. Develop model input capabilities and parameters for temperature distributions.
8. Re-derive the SCFs currently employed in the MOBILE5a model to avoid statistical problems created by normalization.
9. Re-code the MOBILE5a model to avoid double-weighting within model calculations (e.g., weighting model-year BEF by mileage accrual rates and SCF beta coefficients by model-year technology penetration).
10. Provide access to the MOBILE5m through the World Wide Web using a project submission form and e-mail response formats. This would allow the MOBILE5m model to be run remotely over the Internet.
11. Develop incremental hot- and cold-start emission factors (grams/puff) to eliminate problems associated with applying SCFs to FTP composite BEFs. This approach is similar to that employed in California's EMFAC model. A bootstrap approach cannot be meaningfully employed for hot- and cold-start distributions. There is no scientific basis for the use of the hot- and cold-start fraction corrections employed in the MOBILE model: (a) an inherent problem within the EPA methodology is the assumption that all cold-start operations can be represented by the cold-start emissions rates derived from vehicle testing under the Bag 1 cycle of the FTP (assumption has not been validated); (b) studies indicate that cold-start emission rates typically occur over a period of time less than that used in the Bag 1 cycle and that they are very likely to be a function of modal activity; and (c) no interaction effects have been examined between cold-start emissions and other correction factors.

APPENDIX E

THE SPLINE FUNCTION EMPLOYED IN MOBILE5M

A spline function consists of polynomial function pieces joined together under certain smoothness conditions. While a single functional form (e.g., quadratic or cubic) is adopted for all pieces comprising the spline, coefficients of the polynomials are determined for each pair of table points. Judicious selection of the coefficients ensures global smoothness (i.e., for the entire range of table pairs) up to some order of derivative. Cubic splines are one of the most popular interpolating functions that are continuous through the second derivative.

In cubic spline interpolation, a cubic polynomial is used in each interval between two consecutive data points. This cubic polynomial takes the form:

$$y = Ay_j + By_{j+1} + Cy_j'' + Dy_{j+1}''$$

where:

$$A = \frac{x_{j+1} - x}{x_{j+1} - x_l},$$

$$B = 1 - A = \frac{x - x_l}{x_{j+1} - x_j},$$

$$C = \frac{1}{6}(A^3 - A)(x_{x+1} - x_j)^2, \text{ and}$$

$$D = \frac{1}{6}(B^3 - B)(x_{x+1} - x_j)^2.$$

These equations determine the coefficients of the cubic polynomial for any pair of values x_j and x_{j+1}. Another condition is required to ensure continuity across the intervals (xj – 1, xj) and (xj, xj + 1). For j = 2, ... , N – 1:

$$\frac{x_j - x_{j-1}}{6} y_{j-1}'' + \frac{x_{j+1} - x_{j-1}}{3} y_j'' + \frac{x_{j+1} - x_j}{6} y_{j+1}''$$

$$= \frac{y_{j+1} - y_j}{x_{j+1} - x_j} - \frac{y_j - y_{j-1}}{x_j - x_{j-1}}$$

Over the entire range of 1... N, there are N – 2 linear equations in the N unknowns y_i'', i = 1, ... N. For a unique solution, two further conditions must be specified, typically taken as boundary conditions at x_1 and x_N. When one or both of y_1'' and y_N'' equal zero, this solution is termed a "natural cubic spline."

The cubic spline technique is extended in two dimensions to an estimate of $y(x^1, x^2)$ from a large grid of tabulated values. Suffice to say, it is relatively simple to extend cubic spline interpolation to two (or more) dimensions by performing a series of one-dimensional cubic spline interpolations.

The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. The Board's varied activities annually draw on approximately 4,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

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The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation

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2101 Constitution Avenue, N.W.
Washington, D.C. 20418

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