Travel Forecasting Guidelines for Federal and California Clean Air Acts

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Travel forecasting models are being proposed for use in emissions inventories to meet legislative requirements in the federal Clean Air Act Amendments (1990) and the California Clean Air Act (1988). Emissions inventories have requirements for the accuracy and usefulness of the model outputs and the validity of input data and assumptions different from those originally established for travel demand models. The travel forecasting guidelines were developed for the Department of Transportation of the state of California in cooperation with the U.S. Department of Transportation and were designed to meet the legislative requirements in the Clean Air Acts. The development of the travel forecasting guidelines, which involved a series of interactive review sessions with the California Statewide Modeling Group, is described. An overview of the guidelines is presented. These guidelines were developed to represent reasonable travel demand forecasting practice in support of the accuracy required by air quality analysis in four areas: input data and assumptions, travel demand modeling, emissions inventories, and research and recommendations. Since the completion of the travel forecasting guidelines, the document has been distributed by FHWA to all state departments of transportation and to all metropolitan planning organizations that are classified as nonattainment areas. FHWA has suggested that the guidelines be used as a tool for use in conformity analysis. In addition the Office of Traffic Improvement of the California Department of Transportation has distributed more than 300 copies of the report to state and regional transportation, congestion management, and air quality agencies within California.

Travel demand forecasting models have been developed and applied over the past three decades for forecasting travel demand for long-term planning activities such as alternatives analyses, county general plans, and corridor analyses. In recent years these travel demand forecasting models are being proposed for use in emissions inventories, traffic operational analyses, and congestion management planning to meet the legislative requirements in the federal Clean Air Act Amendments (1990), the California Clean Air Act (1988), and the California Congestion Management Program (CMP) (1990). Each of these new uses has requirements for the accuracy and usefulness of the model outputs and the validity of the input assumptions and data different from the requirements originally established for travel demand forecasting models.

The state and federal legislative requirements for modeling, particularly those for California's CMP, have resulted in a proliferation of regional or countywide models. Although regional modeling used to be practiced by only a few metropolitan planning organizations in the state, CMP legislation has led to the development of a countywide model by virtually every county in the state that contains an urban area. Many of the regional or countywide models in the state are reasonably sophisticated and constitute good modeling practice. But some regional agencies are using procedures that have not been updated since the 1960s or 1970s or are using parameters that were transferred from models developed in other areas. As a result there is considerable variation in the level of sophistication and accuracy of regional models within the state. The effort to develop statewide guidelines was designed to raise the overall level of the quality of modeling within the state.

The primary purpose of regional travel modeling in its early applications in the 1960s and 1970s was to determine the need for major highway or transit investments. This determination was most often made on the basis of projected volumes on particular roadway or transit links. When used for this purpose rough approximations of forecast volumes were sufficient to determine when major new widenings or new facilities were needed. With the new regulatory and legislative environment, the use of travel demand forecasts has expanded to include travel speeds and numbers of trips for use in estimating emissions inventories. These additional uses require significantly greater accuracy and sensitivity from the travel demand forecasting models. With the current emphasis on meeting air quality standards within the state, a primary focus in the project described here was to develop guidelines to improve the forecasting of travel activity data as an input to emissions inventories as part of an overall conformity analysis for regional transportation plans and transportation improvement programs.

The legislative requirements have also prompted concern about the consistency of model parameters, assumptions, and results at different levels of government. Regional agencies are concerned about the consistency requirements among the local governments in their areas, and the state agencies are concerned about the consistency of travel demand forecasting models among the regional areas. Greater consistency at all levels of government is desired to facilitate comparisons of forecasts between regions or between agencies within the same region for the process of prioritizing state project funds. To achieve this objective the guidelines establish more consistent methodologies for travel forecasting and more consistent use of assumptions within the travel demand modeling process.

The development of the travel forecasting guidelines involved a series of interactive sessions with an advisory committee that was a subset of the statewide modeling group. The sessions gave the committee members an opportunity to suggest, review, and respond to the topics covered in the guidelines and the establishment of the guidelines. The process included the development of an outline of topics that the guidelines needed to address; the issues addressed are presented in Table 1. Following the presentation of the issues, or topics to be covered, each topic area was researched for current techniques, both nationwide and within California. The research was blended with the authors' experiences

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TABLE 1 Issues Addressed in Travel Forecasting Guidelines

INPUT DATA AND ASSUMPTIONS	TRAVEL DEMAND MODELING	EMISSION INVENTORY NEEDS	RESEARCH AND RECOMMENDATIONS
Socio-Economic Data: • Households, Income, & Auto Ownership • Employment Information • Conformity for Sub-Area Model Special Trip Generators Data External Stations and Trips Network Data: • Transportation Analysis Zones • Highway Networks • Transit Networks Travel Cost Information: • Auto Operating Costs • Parking Costs • Transit Fares • Tolls Calibration and Validation Data: • Traffic Counts • Highway Travel Speeds/Travel Times • Origin-Destination and Trip Length Information • Vehicle Occupancy • Local Trip Generation Surveys	Four-Step Demand Modeling: • Objective • Calibration/Validation Trip Generation: • Trip Purposes • Trip Production Models • Trip Attraction Models • Non-Home-Based Models • State-of-the-Practice Methods • External Trips • Special Generator Trips Trip Distribution: • State-of-Practice Methods • Impedance • K-Factors • Intrazonal Trips Mode Choice: • Discrete Choice Models • Incremental Mode-Choice Models Trip Assignment: • Impedance • Capacity • Highway Assignment • HOV Assignment • Transit Assignment Time-of-Day Distribution Forecasts Feedback Mechanisms Model Applications: • Analysis of TCMs • Congestion Management Regional and Subregional Modeling Model Documentation	Overview: • Historical Development of Emission Estimation Procedures • Sensitivity of Emissions to Travel Characteristics • California's Direct Travel Input Model Trip Volumes by Purpose and Time Period: • Trip Purpose Categories • Time Period Definitions • Travel with External Trip Ends • Special Forecasts • Comprehensive Coverage of Trips Vehicular Speeds: • Relationship Between Speed and Emission Rate • Consistent Use of Speed • Averaging of Speeds • Methods for Validating Speed Estimation Pre-Start and Post-Park Parameters	Institutional and Resource Requirements: • Legislative Requirements • Modeling Coordination Between Agencies • Consistency of Modeling Approach Data Needs: • Land Use/Socioeconomic Data • Network/Supply Information • Cost Information Model Improvements: • Modeling Assumptions • Data Needs for Models • Four-Step Demand Model Improvements • Other Issues Emission Inventory and Other Air Quality Needs: • Comprehensive Coverage of Trips • Prediction of Starts and Parks • Modeling of Weekend and Summertime Travel • Enhancement of Emission Rates Traffic Management and Demand Management Analysis Needs: • Traffic Management • Demand Management Interface Between Land Use and Transportation: • Urban Design Impacts • Transportation's Impact on Land Use

with issues concerning the development of emissions inventories to provide a perspective on the use of travel demand models for the purpose of air quality analysis. The guidelines were then developed to represent reasonable travel demand forecasting practice that could support the accuracy required by air quality analysis. Although the guidelines were developed specifically for the use of travel demand models for emissions inventories, other uses of these models were considered and presented, including congestion management, travel demand management, and facilities planning. Clearly the cost of developing a travel demand forecasting model for any of these purposes precludes the development of a model for a singular purpose. Travel demand models should be developed with all significant purposes in mind to enhance the cost-effectiveness of each individual purpose.

PURPOSE

The driving force behind the development of the travel demand forecasting guidelines was the need to improve the accuracy and consistency of the travel demand models in California for their use in air quality analysis. This led to increasing scrutiny of travel demand models in areas that they were not necessarily designed to address, such as the estimation of accurate link speeds or numbers of trips. For historical transportation planning purposes, the link speeds and numbers of trips were used only as interim measures to validate the volume of travel on the highway or transit networks. Hence the actual estimates of speeds and numbers of trips produced in the travel demand forecasting models were not validated separately from the volume of travel and were perhaps less precise measures as a result. The speed estimated by the model and the total number of trips produced are significant variables in the estimation of emissions inventories, however, and need to be validated for reasonableness in the travel demand forecasting process. Fortunately this is possible with modifications to the existing travel demand forecasting process and additional attention to the validation of these variables.

AUDIENCE

Although the discussions surrounding the use of travel demand forecasting models covered many areas, the modeling advisory committee concurred that the guidelines would apply only to regional travel models (and regional transportation agencies) used in mobile source emissions inventories. For this audience minimum acceptable practice would vary as a function of the complexity of travel behavior in the region and the resources of the agency maintaining the model. This resulted in different standards for small and medium-sized or large regional agencies. The criteria that distinguished the level of complexity of travel behavior within a region were based on travel patterns, size, and air quality.

- Multimodal travel: a significant percentage of the passenger travel in the region is by rail, bus, vanpool, or carpool, and the model is used to estimate the distribution by the various modes;
- Multicounty: the model produces forecasts for multiple counties and serves as a regional model that supports subarea models;
- Population: the model is used for forecasting in a large metropolitan area with multiple employment centers;
- Congestion: the level of service during peak commute periods is significantly different from the level of service in the off-peak periods, and congestion influences route or mode choice; and
- Air quality: the region is a serious, severe, or extreme nonattainment area.

By using these criteria two categories of regional modeling agencies were identified. Those that would be considered complex with respect to most or all of these criteria constitute the first group; the second group would be all other agencies maintaining models for the purpose of emissions inventories or trip conformity analysis. As defined the first group includes the metropolitan planning organizations (MPOs) for the four major metropolitan areas in the state: Los Angeles, Southern California Association of Governments; San Francisco and Oakland, Metropolitan Transportation Commissions; Sacramento, Sacramento Area Council of Governments; and San Diego, San Diego Association of Governments. These four agencies are expected to maintain modeling methodologies more advanced than those of the other agencies in the state. The guidelines developed specify a minimum acceptable standard that would apply to all agencies throughout the state and a more advanced level of acceptable practice that would be expected from the four larger agencies. Whenever possible, however, it is also desirable for the models for small and medium-sized agencies to meet the guidelines for advanced models.

INPUT DATA AND ASSUMPTIONS

The discussion of the input data and assumptions required for the different levels of regional travel models in California provided methodologies for obtaining, estimating, coding, and error checking the data. Input data are required for any application of the model in the base year or a forecast year, and model assumptions are typically estimated for the calibration of the model and are adjusted on the basis of any expectations that they may change over time. Many model assumptions are assumed to remain constant over time. The data sources covered in the guidelines were divided into six sections.

- Socioeconomic data,
- Special trip generators,
- External stations and trips,
- Network data,
- Travel cost data, and
- Calibration and validation data.

The minimum acceptable guidelines in the area of input data and assumptions were similar to those used in the advanced approach except in the stratification of employment data and cost of travel data, for which additional data items are recommended for the advanced approach.

The quality of the input data and assumptions is a significant determinant of the accuracy of the results of the travel demand forecasting model. The source and quality of the input data must be balanced against budget and time limitations. The input data requirements will also vary according to the goals and objectives of the model. Travel demand models that are designed to evaluate transit patronage or the effectiveness of transportation control measures (TCMs) will require more input data than models designed to assess local traffic patterns and flows. There are no definitive criteria for evaluating the cost of developing input data and assumptions versus the benefits of increased accuracy of the models, although there is direction for the evaluation of the accuracy of the models in the guidelines as well as other sources (*1*).

The data sources are given in Table 2 for each category of data. The best source of data may vary from one location to another; Table 2 identifies the best source of data available throughout California. Local sources of data may be more accurate at the traffic analysis zone level, but the data need to be consistent with regional forecasts.

There are three concerns for the development of data bases of socioeconomic data.

- Ability to disaggregate the data into traffic analysis zones,
- Ability to forecast the data, and
- Consistency of the data throughout the region and with state and local agencies.

The validation of the socioeconomic data includes verifying regional data against state and city or county totals, comparing existing data with the forecasted data by area, checking densities by zone for reasonableness, and verifying the balance of jobs with the number of employed residents.

The development of highway and transit networks requires establishment of assumptions that generalize roadway and transit operations to meet regional objectives. These generalizations are necessary to provide cost-effective analysis tools, but need to be considered carefully to prevent oversimplification. The roadway network requires information on the travel time or speed, directionality, number of travel lanes, and capacity on a roadway segment. The travel speed on a segment is a significant variable in determining mobile source emissions, yet travel speed has typically been coded to represent posted speed limits or average speeds stratified by functional class and area type; both assumptions have proven to yield erroneous results on the basis of an individual segment. The guidelines identify the free-flow speed as representing the uncongested travel time with traffic control devices in place (the travel speed on a segment at 3 a.m.). This implies an individual assessment of travel speed for each segment in the regional network, which may prove to be a prohibitively expensive exercise and is not useful for forecasting. Recognizing that certain assumptions can provide a cost-effective solution to coding roadway networks, one must balance these savings with the increased accuracy provided by actual (or accurate) data sources. The guidelines suggest that validation of free-flow and congested speeds is an acceptable method for verifying the accuracy of assumptions made for coding speeds throughout the regional roadway network.

TRAVEL DEMAND MODELING

The guidelines describe the four-step modeling process and methodologies for specifying, calibrating, and validating travel demand

TABLE 2 Sources of Input Data and Assumptions

DATA TYPE	BEST SOURCE(S)	BACK-UP SOURCE	ALTERNATE ESTIMATION
SOCIO-ECONOMIC INPUT DATA SOURCES			
Households	Latest U.S. Census. Split Tracts as necessary.	Aerial Photos and Field Counts	Aerial Photos, building permits, utility company records
Employment	Latest Census Transportation Planning Package (CTPP).	State Employment Office data by zip code. Split zip codes as necessary.	Derive from surveys of floor space and average employee densities.
Median Income or HH Stratified by Income	Latest U.S. Census	Derive stratification from median income	State Franchise Tax Board (Form 540)
Average Persons per HH or HH by Persons/Household	Latest U.S. Census	Derive stratification from ave. population/house.	None
SPECIAL GENERATOR AND EXTERNAL STATION INPUT DATA SOURCES			
External Station Counts	Field Survey for Model (actual counts)	Agency Records	NCHRP 187
Special Generators	Actual Counts	Caltrans Progress Report, Traffic Generators, ITE Trip Generation Manual	None
NETWORK AND TRAVEL COST DATA SOURCES			
Highway Network Characteristics (Capacities, Speeds, etc.)	Field survey geometric and speed data. Use HCM to calculate capacities. Contact local office of state transportation department for HOV facility, park-and-ride lots, and ramp metering data.		
Transit Service Frequencies, Distances, Fares, and Speeds	Transit agency route maps and route schedules		
Cost of Parking	Survey of actual costs paid by parkers	Estimate from average parking fees charged for employer/store subsidies	None
Perceived Auto Operating Costs per Mile	Home interview survey	State or other MPO estimates	U.S. DOT or AAA annual estimates
Speed-Flow Curves by Functional Class	Field survey speed-flow relationships	Use 1995 HCM speed-flow relationships	BPR curve with modifications
Intersection Peak-Period Turn Counts	Field surveys		
Intersection Geometry and Signal Timing	Field Surveys and Aerial Photos		

models. The chapter on travel demand modeling also reports on time-of-day distributions, forecasts, feedback mechanisms, special model applications, regional and subregional modeling relationships, and model documentation. There has been substantial experience with the four-step modeling process in California during the past 25 years. Much of the significant development in the four-step process occurred during the first 10 years of that period, and many existing models in the state are based on a model structure and specifications that are 15 to 20 years old. The most significant advancements in the past 10 years have been in transferring regional models from mainframe computer software to software that can be run on micro- and minicomputer systems. With this transition has come some simplification of the model systems and some enhancement to improve the sensitivity, flexibility, or accuracy of the models.

The guidelines define criteria that transportation models should meet if they are to provide a sound basis for travel demand forecasting. Each model should rely on sound behavioral theory of how individuals or households make travel choices. The structure of choice sequences and the variables used in each model of choices should reflect a logical process of decision making, and the behavioral theory underlying that process should provide a basis for judging the reasonableness of model estimation results. The models, through their input variables, should be sensitive to relevant influences. The importance of this sensitivity is necessary to capture travel behavior and to evaluate alternatives on the basis of changes in policy or exogenous variables. If the models are not sensitive to relevant influences then they are not useful for analyzing alternatives based on these influences, regardless of the precision with which they match base year ground counts. Finally the models should be unbiased. Models are often calibrated to reproduce observed traffic counts or travel behavior, but without regard to behavioral theory or econometric principles. Bias in the model because of improper or incomplete model specification, inaccurately measured input data, or multicolinearity in input variables can result in highly inaccurate forecasts for future years. These criteria for developing and applying travel demand forecasting models are specifically designed to address the predictive capabilities of the models. If they do not capture travel behavior and remain biased then they are not useful predictors of future travel demand.

The guidelines describe each step of the four-step demand modeling process (trip generation, trip distribution, mode choice, and trip assignment) in four parts: a description of the objective of the step, methods for specifications of the modeling procedures, methods for calibrating the procedures, and methods for validating the procedures. Specification of the models is the process of defining the model structure and the econometric methods for estimating the model and selecting the variables for inclusion in the model. Model specification should reflect statistical evaluation, as well as policy direction, to evaluate the most reliable and effective variables and structure to meet transportation agencies' objectives.

Calibration is defined as the process of estimation of the parameters of the model from baseline travel data. The guidelines specify that models should be calibrated from local household survey data every 10 years. This directive is with the understanding that the California Department of Transportation (Caltrans) conducts a household travel survey every 10 years [the latest Caltrans Travel Survey was in 1991 (*2*)] for each region in California that needs to develop regional travel demand models and that Caltrans would provide estimated model parameters and structures to regional agencies that did not have the resources to evaluate in-house the survey data.

Validation of the four-step model is the process of determining the relative accuracy and sensitivity of the model as a forecasting tool. This usually involves the application of the modeling process by using aggregate data sources, representing a current or previous year, and the comparison of the results with actual data collected in the field. When possible validation data sources should be different from those used in calibration, but validation can also include application of the model with the calibration data but stratified by socioeconomic characteristics or geographic subdivision. This provides a test of the sensitivity of the model to variation in input data. Validation may also include checks on the reasonableness of model parameters. This can be done by comparison of model results with results from other models in the state or with reported state or national trends. Validation with actual data sources is often limited to verify the entire four-step process, after trip assignment, but each of the other three steps in the process should be validated for consistency or reasonableness, or both. Each step in the four-step process incorporates the results from the previous steps and should be validated separately to reduce the compounding of errors.

Four-Step Process

Trip generation models should estimate the number of trips by purpose produced by or attracted to a traffic analysis zone on the basis of an econometric relationship of the demographic, socioeconomic, locational, or land use characteristics of the zone. The majority of trip generation models in use today assume that the intensity of travel can be estimated independently of the transportation system or locational characteristics. In California trip generation models are divided into the following areas: home-based trip productions, home-based trip attractions, non–home-based trip productions and attractions, internal/external trip productions, external/internal trip attractions, and external (through) trips.

A central assumption of the trip distribution model is that each traveler making a trip chooses a destination from all of the available destinations on the basis of the characteristics of each competing destination and the relative impedance associated with traveling to each destination. The majority of trip distribution models in California have limited the characteristics of the zone to the most significant factor, measured by the relative attractiveness of a zone or the number of trip attractions. Other socioeconomic factors, such as income or automobile ownership, may influence destination choice and are recommended as areas for further research in applications. The trip distribution model generated considerable discussion in the following areas:

- The use of *K*-factors, or zone-to-zone adjustment factors, that may be used to account for social or economic linkages that have an impact on travel patterns is discouraged because they limit the behavioral response of the trip distribution model in demand forecasting.
- The use of reasonable estimates of intrazonal travel is encouraged to improve the comprehensive coverage of trips required by emissions inventories.
- The value of impedance used in trip distribution should be based on realistic estimates of travel time and speed, should reflect those used in the calibration process, and should reflect congestion through a feedback loop from trip assignment if congestion significantly affects impedance.

Mode choice models separate the person-trip table into the various alternative modes by trip purpose. The available modes have expanded in recent years to include stratifications of the automobile mode by vehicle occupancy (drive alone, two occupants, three occupants, etc.) and the stratification of transit modes into transit technologies and types of operation (local bus, express bus, light rail, heavy rail, etc.) and types of access (walk or drive). The mode choice model should include significant variables, such as income, automobile ownership, travel time, and cost, and provide sensitivity to policy variables, such as parking pricing, carpool facilities, or time of travel. A simplified mode choice approach is acceptable if the regional agency is not testing the sensitivity of carpool or transit policies. Policy-sensitive variables may be tested in a postprocess to the mode choice model to account for policy variables that cannot be well represented in travel demand models. Larger metropolitan areas should evaluate nested logit model structures to evaluate carpool alternatives or multimodal transit systems.

Feedback Mechanisms

There was considerable controversy among the advisory committee as to the appropriate and reasonable use of feedback mechanisms in demand forecasting models. Feedback mechanisms represent the equilibration of impedance at one or more steps in the modeling process, as shown in Figure 1. Impedance is a function of the travel time and cost from the origin to the destination of a trip and is derived from the transportation system characteristics in response to demand patterns. Although the cost of a trip is generally fixed, the travel time is variable depending on the congestion on the facility at any particular time of day. There are assumptions made throughout the travel demand forecasting process concerning travel time, or speed, that may be affected by the time of travel or the estimated impacts of congestion.

Travel speed is unique among model variables because it is both an input and an output of single modules within the travel demand forecasting model. Travel speed is used as an input in the trip distribution model to estimate the impedance from one analysis zone to another. Speed is used as input to the mode choice model to determine the impedance differential between highway and transit travel choices. Finally travel speed is an input to and an output of the trip assignment model, which analyzes the "free-flow," or input, speeds and the travel volumes to produce the "congested," or output, speeds for the roadway system. There is significant controversy about the consistent use of speeds in the travel demand forecasting process. Some agencies use free-flow speeds in the trip distribution model to estimate the distribution of trips in the transportation network, regardless of congestion, mode, or average delays. Larger agencies have incorporated an estimate of congested speeds in the distribution model applied to trip purposes in the peak period. The mode choice model typically assumes that all home-to-work trips are traveling in the peak period and encounter congested speeds, whereas all other trip types travel in the off-peak period and encounter free-flow speeds. The controversy identifies the discrepancy between assumptions made at different points in the travel demand forecasting process relating to travel speeds.

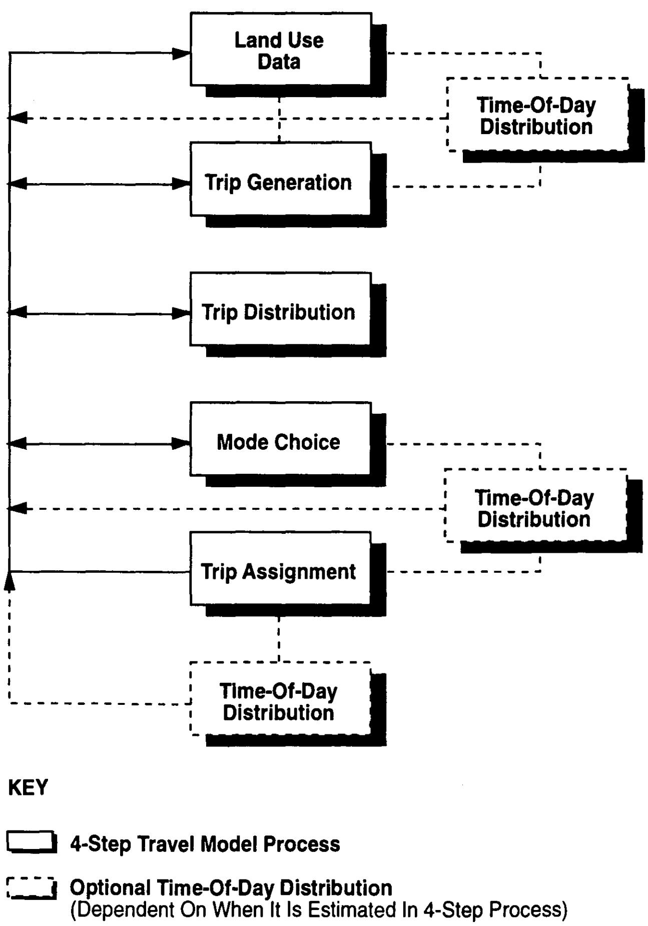

FIGURE 1 Feedback mechanisms to equilibrate impedance.

- The estimation of land use data and trip generation is not significantly affected by travel speeds.
- The estimation of trip distribution is not significantly changed by the deterioration of travel speeds in the peak period, that is, congested travel speeds versus free-flow travel speeds.
- Mode choice for work trips is significantly influenced by congestion in the peak period, and mode choice for other trips is influenced only by off-peak travel speeds, which are typically not affected by congestion in the models.
- Route choice estimated in the trip assignment model is significantly affected by the deterioration of travel speed because of congestion.

Much of the discussion on feedback mechanisms of impedance leads to a need for further research for the benefits of incorporating feedback mechanisms versus the costs associated with the equilibration required in the modeling process. A significant portion of the costs involved will result from the need to recalibrate each model after incorporation of feedback loops (*3*).

EMISSIONS INVENTORY NEEDS

In California emissions inventories are developed by applying to travel activity data emissions rates estimated by average speed and vehicle classification. The development of these emission rates from the federal test procedure (FTP) and other cycles has provided a capability to estimate emissions from link-specific volumes and speeds produced by regional travel demand models. In previous years emissions inventories focused exclusively on vehicle miles traveled (VMT) and average link speed (a measure of running emissions) as determinants of emissions. Despite the extensive use of the FTP driving cycle and speed-based emission rates produced from it, the Environmental Protection Agency and the California Air Resources Board (CARB) continued research to identify the more specific determinants of the variations in emission rates. The result of the research has been an identification of four specific categories for vehicle emissions:

- Trip start emissions (cold start or hot start, depending on the period for which the vehicle has been turned off),
- Hot stabilized running emissions (exhaust and evaporative),
- Hot soak evaporative trip end emissions, and
- Diurnal emissions (hydrocarbon emissions from evaporation that are essentially unrelated to the amount the vehicle is driven).

The relative significance of each of these emission categories, which are also referred to as *impact-producing processes*, is demonstrated in Figure 2.

The California emissions rate model, EMFAC7E, produces rates in grams per hour by dividing by the speed (in miles per

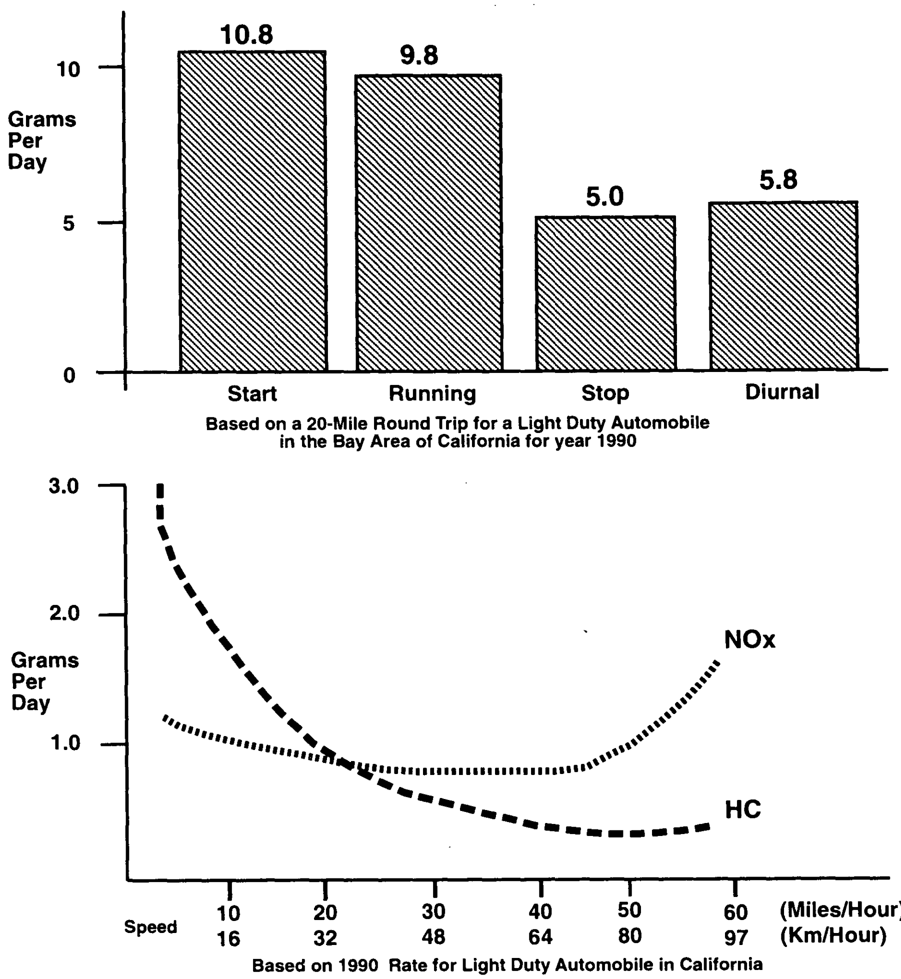

FIGURE 2 Relationships of trips, VMT, and speed to emissions.

hour). The rates can be converted to a grams per mile basis like those also illustrated in Figure 2, but the relationship is undefined at a speed of zero (*4*).

The guidelines for emissions inventory analysis in California have been established by the statewide use of the Direct Travel Impact Model (DTIM) (*5*). The methodology contained in DTIM represents the most sophisticated approach to using regional travel model output to produce emissions inventory data for on-road motor vehicle activity. Because of its sophistication and widespread use the input requirements of DTIM define the acceptable level of practice for California.

Trip Volumes by Purpose and Time Period

Accurate prediction of the air quality impacts of on-road motor vehicle activity is critically dependent on accurate prediction of trip volumes by purpose and time period. If trip purpose is used to estimate time-of-day and vehicle type distributions, at least three trip purposes should be used. The definition of time period should be designed to capture homogeneous characteristics of travel such as congestion, mix of trip purpose, and travel speeds. Whenever congestion has a significant impact on peak-period speeds, peak periods should be modeled separately. Emissions are sensitive to the time that the emissions occur for two reasons: the ambient temperature (at a specific hour of the day) under which a vehicle has been started will affect the start emissions, and the time at which emissions are produced will affect the maximum concentrations and locations of pollutants.

The estimation of trip volumes for emissions inventories should consider two areas that are not typically considered in travel forecasting models:

- Special forecasts (seasonal, day of week, or special event variations) and
- Comprehensive coverage of trips (short trips; truck, recreational, or school trips; or transit vehicle trips).

The most common practice in California is to calibrate regional travel forecasting models for average annual weekday travel. If the emissions inventory is estimating travel for weekend days in a particular month, corrections to the modeled trip volumes should be made on the basis of the observed seasonal and day-of-week variations. Also whenever special events are known to have a significant impact on an emissions inventory, external adjustments should be made to the travel activity data to reflect the impacts of those events.

There are many types of trips that have typically been excluded from regional travel forecasting models because they were not significant for the evaluation of transportation infrastructure needs, which was the main objective of these models. Shorter trips, often defined as intrazonal trips for modeling purposes, are typically excluded from trip assignment because the modeled highway network was not detailed enough to evaluate these trips, but these trips are significant for emissions inventories and need to be included. Certain trip types, such as truck, school, or visitor trips, are frequently underrepresented or excluded from modeling but need to be included in an emissions inventory.

Vehicular Speeds

Emissions rates developed by CARB represent an average rate on a grams-per-hour basis over a range of operating modes (acceleration, deceleration, cruise speed, and idle). To be consistent with the emission rate models, it is critical that the vehicular speeds estimated in the travel forecasting model also represent an average operating speed over a section of a facility, not the midblock cruise speed or the speed limit on the facility. A postprocess to evaluate an hourly variation in speeds may be warranted to provide additional accuracy for emissions inventories and would not need to be implemented within the regional travel forecasting model. Speed should be estimated for emissions estimation purposes in as detailed a manner as is practical and consistent with the definition of speed used in emission rate models.

The nonlinearity of the relationship between speeds and emissions rates introduces a concern about the effects of averaging speeds across time periods or vehicle classifications. This is a common practice in travel forecasting, but it should be minimized when the speeds are to be used in emissions estimates. Also, emissions rates increase with speed for higher speeds (over 50 mph), which means that the model needs to be accurate for these higher speeds. Many travel forecasting models constrain the free-flow flow speed on a link to the speed limit, when in reality the observed free-flow speeds under uncongested conditions on the facility may exceed the speed limit.

RECOMMENDATIONS FOR RESEARCH

During the development of the travel forecasting guidelines for California many of the discussions among the advisory committee focused on recommendations for further research. Six topic areas for further research were identified:

- Institutional and resource requirements,
- Data needs,
- Model improvements,
- Emissions inventory and other air quality needs,
- Traffic and demand management analysis needs, and
- Interface between land use and transportation.

The recommendations identified specific, achievable tasks for improving the use and understanding of regional travel forecasting models used for air quality analysis in California.

Three considerations for institutional and resource requirements would benefit from additional information, further research, and a better understanding of the requirements. The legislative requirements are complex and extensive, requiring effort to learn and understand the benefits and costs of each legislative requirement. The modeling coordination between agencies is required by legislation, but the interpretation of what constitutes coordination is flexible. The consistency requirement of the legislation will improve the comparison of transportation impacts from one area to another and may improve the reasonableness of individual modeling assumptions.

The research needs for data are identified in three topic areas that need further research:

- Land use and socioeconomic data (employment stratified by income, land use allocations, role of accessibility, job and housing balance),
- Network supply information [geographic information systems (GISs), traffic counts, pavement conditions, turn penalties, ramp meter delays], and
- Cost information (automobile operating costs, parking cost forecasts).

These research needs are based on the authors' experiences with the areas of potential weakness in current travel forecasting techniques and the areas for which the greatest payoffs (in terms of improved travel forecasts) will be achieved with new research.

Research needs for four-step travel forecasting models were identified in four areas:

- Validation of modeling assumptions,
- Data base management and GIS tools for models,
- Four-step model improvements (impedance in trip generation, choice-based distribution models, socioeconomic variable in distribution, composite costs, walk and bike trips and multimodal trips, and feedback mechanisms), and
- Other research needs (changes in travel behavior over time, limitations on the size of transportation system, cost of model improvements versus accuracy, multiple-purpose trips, intelligent vehicle-highway system evaluation).

Research is ongoing in each of these areas, and in some cases there have been tests to evaluate this research, but none of these areas has been incorporated into the state of the practice in California. In addition to the benefits of this research for air quality analysis much of this research would benefit travel forecasting models for use in other types of analysis.

Adoption of the federal Clean Air Act Amendments of 1990 has renewed interest in the use of regional travel models in developing emissions inventories and in predicting the impact of growth and transportation projects on air quality. Although it is generally recognized that regional models are essential in developing the data for air quality analysis, it is also recognized that there are certain limitations in the models that affect the accuracy of the emission estimates produced from their output. New research is warranted to adapt the regional models more specifically to emissions estimation:

- Comprehensive coverage of trips,
- Prediction of starts and parks (on the basis of limited survey data, differentiate hot and cold starts),
- Modeling of weekend and summertime travel (when ambient air quality standards are violated), and
- Enhancement of emissions rates (which vary by facility type).

As the opportunities to build new highway facilities or widen existing facilities in congested urban corridors have decreased, focus has shifted to transportation management options to accommodate travel demand. Many regional models that were sufficiently sensitive for analysis of new facilities or for significant widening of existing facilities are now insufficient for traffic management and demand management analyses. Substantial research and development are needed to improve the sensitivity of regional models to these increasingly popular options.

With the growing recognition that increasing travel demand from growth cannot be accommodated with new facilities, interest has turned to reducing the amount of new travel from growth by changing the nature of development. There is also concern that the development of new transportation facilities can influence the amount and location of new development and thereby induce growth in travel by the supply of transportation facilities. Both of these are areas in which new research is required if regional forecasting models are to be sensitive to the interaction of land use and transportation.

SUMMARY

There is growing concern in California that state-of-the-art transportation models produce inconsistent or unreliable data for use in mobile source emissions inventories. The current analytical methods used vary from one region to another and vary in detail and complexity for small, medium, and large regions throughout the state. This has a direct impact on the conformity process for regional transportation plans and regional transportation improvement programs. From a statewide perspective it would be desirable if all agencies used consistent methodologies in travel demand modeling and produced reasonable results. The travel forecasting guidelines provide direction and guidance to regional transportation agencies throughout California in the areas of data sources, modeling assumptions, and results to achieve this consistency.

The travel forecasting guidelines provide specific guidelines separate from the supporting documentation for clarity. In addition the current state of the practice and what constitutes good practice are identified for further information. Although the document was oriented to regional transportation agencies, it is expected that a variety of other audiences may find it useful. These might include executive management officials determining whether existing modeling practice is acceptable or technical staff evaluating their own modeling capabilities. For these audiences, the guidelines can be used for a number of purposes, including the following:

- Ensuring that modeling is performed correctly;
- Achieving a minimum acceptable level of accuracy;
- Providing some standardization and, through it, better understanding of the modeling being performed;
- Adopting universally accepted definitions and terms;
- Meeting the requirements of specific legislation in the state; and
- Conforming to what might be established as a legal basis for acceptable practice.

Forecasting of travel behavior involves representation of numerous complex decisions, and forecasts can only be expected to roughly approximate reality. The state of the art in travel forecasting continues to improve as individuals pursue new methods for analytically representing the complex decisions being made. Although the guidelines are intended to provide some degree of consistency through standardization of methodology, they are not intended to stifle the creativity that will ultimately lead to improvements in the practice. The guidelines are designed to represent a minimum level of acceptable practice and as such are designed to establish a minimum level of consistency and accuracy. To provide this desired consistency without restricting creativity, the guidelines focused on the principles of good forecasting practice rather that specifying which methods should be used.

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