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Development of an Improved Framework for the Analysis of Air Quality and Other Benefits and Costs of Transportation Control Measures

This NCHRP digest summarizes the findings from Phase I of NCHRP Project 8–33, "Quantifying Air Quality and Other Benefits and Costs of Transportation Control Measures." The objective of Project 8–33 is to develop an improved analytical framework for evaluating transportation control measures. The objectives of the particular tasks summarized in this digest were to outline the desirable long-term characteristics for an improved analysis framework and to identify techniques that could be implemented immediately by state DOTs and metropolitan planning organizations. The framework described in this digest is being tested and refined in subsequent phases of the research. This digest is based on two separate interim reports prepared by Cambridge Systematics, Inc.; Envair; Sierra Research, Inc.; Deakin Harvey Skabardonis, Inc.; and others. John H. Suhrbier of Cambridge Systematics is the project's principal investigator.

INTRODUCTION

This digest describes improvements to the traditional transportation planning process that will enhance air quality and other analyses. This digest will be particularly useful to planners considering upgrading their process. The Clean Air Act Amendments of 1990 (CAAA) and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 created numerous analytical challenges for state DOTs and metropolitan planning organizations (MPOs) in their attempts to evaluate transportation control measures (TCMs) and to conduct associated transportation air quality analyses. Although examples of both good and improved analyses can be cited, there are many examples where the underlying analysis is deficient in one or more respects. Given such deficiencies combined with improvements in the understanding of transportation, emissions, and air quality interrelationships, a fundamentally new analytical framework needs to be developed over the coming years to conduct TCM and related transportation air quality analyses (Figure 1).

The basic characteristics of the current set of analytical methodologies used by transportation agencies to support the requirements of the CAAA and ISTEA were developed more than 20 years ago. Furthermore, the transportation, emissions, and air quality components were developed largely independently of each other and for basically different purposes than the ones for which they are now being used. For example, transportation models—developed to support the design and construction of new or expanded infrastructure—are serving as the basis for spatially and temporally distributed emission inventories. Although the resulting sequence of linked models produces numbers, there is serious concern about the accuracy of these results, the robustness of the underlying data, and whether the correct set of variables are captured in the model systems representing current practice. In addition, scientific knowledge of U. S. air pollution problems, especially with respect to particulate matter (PM) and ozone, continues to improve. As a result, renewed attention is being given to the potential impacts that various forms of air quality transportation control strategies may have on ambient pollution levels.

The objective of NCHRP Project 8–33 is to develop and test an improved analytical framework for analyzing air quality TCMs. Emphasis is being given to identifying the important causal variables, examining their inherent uncertainty, and determining the degree to which they are correctly represented in current analysis procedures.

The proposed analytical framework is being developed with different time frames in mind so that a longer term "ideal" in terms of what is needed to best model transportation emissions and air quality impacts can be balanced with what is "realistic" in terms of specific techniques that can be developed, implemented, and applied practically and within nearer term time horizons by transportation and air quality agencies. As illustrated in Figure 2, a long-range time horizon is used to define new analysis approaches that may be possible using information and analytical technologies that are likely to become available in coming years. This long-range or "ideal" future is then used to prioritize the changes that are desirable for more intermediate time horizons. The long-range analytical framework can be characterized as one that fully uses emerging electronic information technologies. It also may not necessarily be driven by analytical requirements specified in the 1990 CAAA and associated regulations and guidelines. Although the full complement of these analytical capabilities may not be available for more than 10 or even 15 years, these capabilities indicate the direction in which transportation air quality research should head.

Although attention should be given to the long-range research and development activities necessary to develop a fundamentally improved analytical framework, numerous enhancements can be made immediately to existing analysis approaches that will improve the accuracy of estimated emission and air quality impacts. These improvements in accuracy can be achieved by focusing on those variables (e.g., vehicle speed and acceleration) that link transportation, emissions, and air quality and by examining the spatial and temporal distribution of emissions from transportation sources.

TRANSPORTATION ACTIVITY DATA

Significant attention is being given to how both existing and new transportation infrastructure is being managed. As a result, an entirely new generation of transportation management strategies is being considered and rapidly deployed. These include intelligent transportation systems (ITS), a diverse array of market-based pricing mechanisms, land use and growth management policies, alternate work or trip schedules, and the use of information technologies as a substitute for travel. Each of these emerging strategies and technologies has important implications for the volume and schedule of travel and thus for the efficiency of both vehicle and system operations.

The emission and air quality characteristics of these new strategies are only now beginning to be understood. Two points, though, are clear. First, future transportation air quality analyses must not be limited to traditional forms of TCMs such as high-occupancy vehicle (HOV) lanes, park-and-ride lots, carpooling, vanpooling, and public transportation. Second, the improved transportation air quality analytical methodologies being developed in this and parallel research programs must be responsive to the characteristics of these new transportation management strategies.

In analyzing both innovative and traditional types of transportation air quality control strategies, the transportation modeling step provides the set of vehicle activity data used in the subsequent emissions and air quality steps of the overall transportation air quality modeling chain. As such, the accuracy of the estimated emissions and air quality impacts can be no better than the accuracy of the underlying transportation information. The following information emerged as being high-priority products of the transportation portion of the analysis:

- Data on the length and timing of individual trips in addition to aggregate link vehicle miles of travel (VMT);
- More accurate estimates of the spatial and temporal distributions of travel;
- Increased data on the characteristics of the vehicles being used for particular trips; and
- Improved information on freight trips, particularly heavy-duty diesel trucks and locomotives.

The modeling of person travel, as represented by the traditional four-step process, is more focused on simulating flow volumes than on realism in behavioral choices. Whereas travelers typically make decisions regarding time, place, cost, mode, route, and so forth almost simultaneously, the structure of the standard four-step process treats these choices as being "sequential" and generally without much sensitivity or realism in relation to "policy" variables. Although "feedback" features increasingly have been introduced into these four-step modeling systems, important limitations still exist with respect to the analysis of TCMs and, especially, the emerging forms of transportation management strategies.

With respect to freight, goods movement is typically not addressed as an integral part of urban transportation planning and is not directly represented in existing standard transportation modeling systems.

It is recommended that the person travel portion of an improved transportation air quality analytical framework ultimately be built on a combination of the following analytical modules:

- A system of disaggregate and activity-based travel demand models;
- Use of sample household enumeration techniques;
- Increased use of an incremental forecasting approach where emphasis is placed on the specific market segments affected by a change;
- Traffic microsimulation; and
- Household travel surveys containing stated as well as revealed preference data.

Although each of these five modules exists individually today, they have not yet been fully and effectively integrated into a production-oriented transportation analysis system that is practically available to state DOTs and MPOs. Further, some of these modules are in the relatively early stages of research and deployment, especially activity-based travel demand modeling.

Disaggregate and Activity-Based Demand Models

An examination of ongoing transportation research indicates a dramatic trend toward the increased use of disaggregate and activity-based analyses. These analyses are likely to become the modeling norms of the future, though, it is not clear how long this transition will take. These newly emerging modeling approaches focus on the individual, household, vehicle, and trip—rather than aggregate groups of households or areawide VMT used in more traditional approaches.

Today's modern disaggregate travel demand model systems have evolved from the standard four-step approaches of the 1960s and 1970s. Increasingly, travel demand analyses are incorporating estimates of the level, type, and age of vehicles owned by a household. Trip frequency and destination are estimated simultaneously rather than independently, and this simultaneous choice analysis may include mode of travel as well. Nonmotorized modes of travel, such as bicycling and walking, are being integrated into urban area travel analyses so that the full spectrum of shorter trips can be analyzed. Individual trips are linked so that entire travel chains can be analyzed. Trip information is derived from the demand for individual activities, thereby permitting the improved analysis of TCM impacts.

Ozone dispersion models, such as the Urban Airshed Model, can be characterized as hour-by-hour simulations of the chemical reactions occurring within individual three-dimensional grid cells. Activity-based travel analyses simulate individual daily activity patterns and, ultimately, will include activities that do not involve actual travel.

Household Sample Enumeration

The use of disaggregate and activity-based analyses facilitates the use of sample-based analysis and forecasting approaches that are based on the individual, household, and vehicle rather than the traditional aggregate traffic analysis zones (TAZs). This means that entire trips can be easily identified and tracked—this is preferable to analyzing emissions and air quality analysis (based primarily on link traffic volumes). The STEP model is an example of a random sample household enumeration analysis approach. Initially developed in the 1970s to evaluate candidate transportation energy conservation measures, this modeling approach has been used recently throughout the country to evaluate various forms of congestion pricing. A significant advantage of this analytical approach is that the focus is on individual activities and trips rather than on aggregate travel.

Current travel demand models are based on the concept of TAZs. To develop an aggregate estimate of either current- or future-year conditions, a set of relatively homogeneous TAZs is defined. Each TAZ is characterized then by a set of average conditions and aggregated into an estimate for the larger geographic region being modeled.

Household sample enumeration is an alternative aggregation approach and a key factor in improving the transportation output for emissions. A sample of the population—the "prototypical sample"—is used to represent the entire population. This group is expanded, through the application of weights if a stratified sample is being used, to represent the total population. On the basis of the characteristics of this sample (e.g., income levels, work status, and household composition), decisions on different aspects of travel behavior (e.g., vehicle ownership, mode choice, frequency of trips, time of day of trips, and destinations) can be predicted based on the model system.

Aggregate forecasts are made by applying the disaggregate models to each household in the sample. By estimating an appropriate set of expansion factors, the prototypical sample can be used to make forecasts for the entire population and can represent virtually any demographic and economic scenario of interest. In this approach, the activity of each household can be tracked. If the models include type of vehicle owned and used, the specific vehicle used for each trip can be identified for emission and air quality purposes.

Incremental Analysis

Travel models can be applied incrementally to estimate a change rather than an absolute value. Instead of using the models to predict future-year travel demand, they are used to predict changes from a base year. These changes are applied then to the base year to obtain future-year forecasts.

For travel demand models, the general idea of the incremental approach is to use the forecast of changes in land use, socioeconomic characteristics, and level of service to forecast changes in trip tables from the base year to a future year. This difference is then added to the base condition table to produce a changed or future condition. Incremental or pivot-point modeling is incorporated in the FHWA/FTA TDM model and was integral to early U. S. Environmental Protection Agency (EPA) sketch planning methodologies. Originally applied only to mode choice, recent applications have extended the concept of incremental analysis to trip tables.

The incremental approach can be expected to produce a high degree of accuracy for most forecasting applications because it is based on differences from a well-calibrated, accurate base condition. A common problem with traditional modeling techniques is that numerous variables affect the travel behavior of individuals. The complexity of travel behavior makes it extremely difficult to develop and calibrate a statistical model of existing travel patterns. Therefore, although all the elements of the traditional modeling approach appear in the incremental approach, the focus is shifted from the models to well-calibrated base-year trip tables. The multiple dimensions of this trip table represent many trip characteristics such as travel mode, time of travel, and purpose of trip. The assumption is that these trip tables capture behavioral issues that cannot be fully explained by the models. These unexplained behaviors are assumed to continue to exist in the future. Therefore, instead of relying completely on the models to develop future-year trip tables, the models are used only to identify changes from the base year to the future year, and these changes are then added to the well-calibrated base year to obtain forecasts. The adequacy of this approach depends on the adequacy of the base-year trip table, which in turn depends on the availability of sufficient travel behavior data and traffic counts.

Traffic Microsimulation

Mobile source emissions are a function of vehicle speed-change cycles, acceleration, and other vehicle operating characteristics. The proposed improvements to the transportation air quality analysis framework, therefore, include analysis approaches directed at the following objectives:

- Improve current transportation model output by accurately modeling the effects of traffic congestion (i.e., accurately predict traffic volumes, speeds, delay, and queuing) and
- Provide the capability to output vehicle operating mode (e.g., acceleration, cruise, deceleration, and idle).

There has been considerable growth in the use of traffic micro- and macro-simulation capabilities as a result of the increased interest in traffic operations and congestion management. It is now relatively common to use linked analyses where the results of a travel demand analysis are fed into a traffic simulation analysis, but without any feedback of the traffic simulation results into the demand analysis. Although traffic simulation and travel demand analyses have been integrated on an experimental basis, this integration is not yet common. Such integrated analyses are likely to become common in the coming years.

Household Travel Survey Data

Travel demand models use data derived from different travel surveys and data collection efforts. Among these, the household travel survey is particularly useful for developing an improved transportation air quality analysis framework. Additional data can be extracted from earlier household travel surveys. New household travel surveys can be designed to include additional air-quality-related information, especially with respect to vehicle characteristics.

The level of detail that will be possible in any improved travel model system depends on the characteristics of the household travel survey. Ideally, a full disaggregate travel model system could be estimated on the basis of a new household survey. If data are more limited, travel models can be transferred from other locations and calibrated on the basis of an existing household survey. Usually, household surveys have to be expanded using other surveys, such as transit on-board, external station, and commercial vehicle.

Possible air quality extensions for household travel surveys are the inclusion of information about trips in different seasons, additional vehicle data, and information on weekend trips. Most household surveys exclude summer days because summer, which does not provide a typical travel pattern, it is not the critical season for transportation design purposes. Peak ozone conditions, however, typically occur during the summer. Another important detail for air quality purposes is the class of vehicle used for each trip. Some household surveys are beginning to ask questions about the specific vehicle used for a particular trip, but very few, if any, are yet using this information in their travel model systems even though emissions may vary by vehicle age, type, and mileage accumulation. Ozone episodes may extend into a weekend, so differentiating weekend from weekday travel characteristics may be important.

Another extension to current household survey practice is to include stated preference questions regarding TCMs and policies that cannot be modeled through revealed preference data. Examples of such TCMs are telecommunication and the introduction of new travel modes or electric vehicles. Although stated preference surveys have been subject to considerable error and overestimation bias, techniques have been introduced recently that reduce these problems and also integrate stated and revealed preference survey data. An additional improvement in household surveys is the use of panel surveys, which can improve the ability to analyze a wide range of TCMs, including monitoring the effectiveness of implemented TCMs.

EMISSIONS MODELING

The MOBILE model developed by the EPA and the EMFAC model developed by the California Air Resources Board (CARB) are the emissions factor models currently used to produce fleetwide emission estimates. Generally, MOBILE and EMFAC are referred to as "regulatory models," because state implementation plans (SIPs) and related conformity and National Environmental Policy Act (NEPA) analyses are required to use one of these emission factor models.

Numerous concerns about the performance of these regulatory models have been raised in recent years. The accuracy of the estimated magnitude and distribution of emissions depends on the accuracy of the underlying vehicular emission rates. Improving the accuracy of the transportation models will accomplish little if the emission models are not simultaneously improved.

Key emissions modeling issues, from a transportation perspective, include

- **Representativeness of the Federal Test Procedure (FTP)**—Data collected during the past few years indicate that the driving cycles on which the MOBILE and EMFAC models are based do not accurately reflect the types of vehicle operation that occur under typical in-use conditions.
- **Representativeness of Speed Correction Factor Test Cycles**—Many of the test cycles used to construct the speed correction factors are not representative of in-use driving conditions.
- **Limitations of Speed Correction Factor Methodology**—Under the vehicle emissions modeling approach used in MOBILE and EMFAC, the effects of changes in traffic flow characteristics on emissions are based solely on the basis of changes in average speed. This is a one-dimensional approach to a multidimensional problem and cannot adequately describe the underlying distribution of speeds and accelerations that vary by type of facility and level of congestion.
- **Use of Trip-Based Emission Estimates to Characterize Link-Specific Emissions**—The use of FTP-derived emission rates in combination with speed correction factors may not be appropriate for estimating emissions for individual segments of the roadway system.

The MOBILE and EMFAC models are being used not only to evaluate individual roadway improvement projects, but also to develop and evaluate transportation policy. The simplistic assumptions built into the models regarding the relationship between average speed and vehicle emissions do not enable the models to be used reliably to evaluate operational improvements that smooth traffic flow (e.g., ramp metering, signal coordination, and many ITS strategies). To the extent that such operational improvements reduce acceleration events and the queuing of vehicles, they may produce emissions benefits that are inconsistent with estimates based on the use of the speed correction factors built into MOBILE and EMFAC.

Table 1 is a prioritized listing of the data desired for modeling emissions from on-road motor vehicles, with a particular emphasis on the parameters needed to estimate the emission impacts of TCMs. Considering all pollutants, VMT is the most critical piece of information in a modeling effort. Errors in these estimates directly affect the emission calculation because emissions are calculated as the product of VMT (obtained from transportation models) and gram per mile (gm/mi) emission rates (obtained from emission factors models). Also of note in the table is that the priority of data needs for volatile organic compounds (VOCs) and carbon monoxide (CO) emission estimates are generally similar. This is because VOC and CO typically are related more to light-duty vehicle travel, their sensitivity to ambient temperature is similar, and their formation in the engine is often tied to specific operating modes (e.g., during cold start). However, heavy-duty diesel vehicles are significant contributors to nitrous oxides (NO_x) and PM, and NO_x is less sensitive to ambient temperature.

As illustrated by Table 1, various transportation data are needed to characterize on-road motor vehicle emissions accurately. Many, but not all, of the identified parameters generally are available from today's transportation models. The following are important exceptions; data or modeling improvements in these areas would be particularly beneficial:

- **Speed/Acceleration/Driving Profile**—Although speed is an input to emission factor models, acceleration and driving profile are not. These parameters (in particular, acceleration) can have a significant influence on emissions.
- **Fraction of Cold/Hot Starts**—This is an important parameter used by emission factor models. Vehicles in the cold-start mode generally have emissions that are several times higher than during warmed-up operation.
- **Travel by Vehicle Class and Time of Day**—Travel by vehicle class can be specified by the user as an input to MOBILE. However, most analyses let the model calculate this parameter based on forecasts of national vehicle populations and assumed VMT by vehicle class. This is an area in which improvements can be made and linkages with transportation models may help. In terms of travel by time of day, these data would be of help in better estimating temporally distributed emissions.
- **Time/Location of Starts**—This is not a direct input to emission factor models, but information on the time and location of starts can be used in conjunction with emission factor model output to better estimate spatially and temporally distributed emissions.
- **Travel by Facility Type and Time of Day**—The distribution of travel by vehicle class is not constant across facility types. Because different facility types have different patterns of travel, average speed, and driving profiles, information specific to facility types could be used to better estimate motor vehicle emissions. As currently structured, however, emission factor models can only accept average speed as an input parameter.
- **Trip Ends with Hot Soaks**—The location of trip ends would allow better spatial allocation of VOC emissions for input to airshed models. Current emission factor models, however, are not used directly for allocating emissions spatially.
- **Freight Mode (Truck Versus Rail)**—Goods movement via truck can have an important impact on NO_x emissions in an urban area. Although motor vehicle emission factor models are not equipped to handle rail emissions, they can be better used to generate vehicle class-specific emission factors to make comparisons with rail travel.

Both the EPA and CARB recognize the problems associated with using MOBILE and EMFAC to estimate the effect of transportation system improvements. Both agencies are collecting data and developing new analysis techniques to improve the performance of the existing models.

Independent of the improvements to the MOBILE and EMFAC regulatory models, several efforts are underway to develop an entirely different class of emission model—referred to as "modal emission" models. A major objective of these efforts is to overcome the assumptions embedded in the current regulatory models regarding the relationship between average speed and emissions. The scope of existing regulatory models vis-à-vis modal emission models can be differentiated as follows:

- **Existing Regulatory Models**—Base emission rates for all vehicles making up the vehicle fleet (e.g., vehicle classes, model years, technology categories, age, and mechanical condition) are derived from emission measurements from a single representative driving profile (i.e., the FTP). A series of correction factors is used to adjust these estimates to account for differences between the FTP drive cycle and design-day conditions of a specific community (e.g., speed, temperature, and hot/cold-start fractions).
- **Modal Models**—Analysis is performed to identify the modes of vehicle operation responsible for significant differences in emission performance. Tests are then performed to measure emissions from these modes of operation for a sample of vehicles that represents the in-use fleet. The following different approaches are being used to characterize the range of in-use emissions performance:

- In-use driving data are analyzed to develop multiple driving cycles to characterize vehicle operation by facility type and level of congestion. Emission measurements are taken for a representative sample of vehicles tested on these alternative cycles. Travel activity is segregated by facility type and congestion level and combined with the appropriate emission factors to quantify emission estimates.
- Emission measurements are taken for each mode of speed and acceleration for a representative sample of vehicles. This approach is based on steady-state measurements of emissions at fixed speed and acceleration points (i.e., the transitional impacts of acceleration or deceleration, which can be considerable, are ignored). To prepare emission estimates, travel activity for the entire vehicle fleet must be supplied in units of time at these modes of speed and acceleration.
- Emission measurements are taken for a representative set of engine speed and load points (commonly referred to as engine maps of emissions) to characterize the range of engine operation and related emissions performance for a representative sample of vehicles. A computer model is used to translate second-by-second driving activity into engine power demands. The power demands then are matched with related emissions estimates (in most cases, these estimates must be interpolated because test measurements are limited) to generate estimates of in-use emissions.

Although considerable attention is being given to the development and testing of modal emission models, enhancements will continue to be made in the coming years to the MOBILE and EMFAC regulatory models. The CAAA requires the EPA to update its emission factor estimates for VOC, NO_x, and CO at least every 3 years. In addition, significant attention is now being given to the development of MOBILE6 as the immediate replacement for the MOBILE5 emissions factor model. Although CARB is under no such legal mandate, practical considerations dictate a similar, but not necessarily parallel, schedule of improvements.

AIR QUALITY

An important objective of Project 8–33 is to develop an analytical framework that more directly relates both traditional and innovative TCMs to modeled and monitored ambient air quality levels than now exists. The project's initial work made clear that improving the accuracy with which the magnitude and the associated temporal and spatial distributions of emissions are calculated is important in accomplishing this objective.

The pollutants of primary concern for transportation purposes are ozone, fine particles (primary and secondary), CO, NO_x, and VOCs. In analyzing the effects of transportation actions on these pollutants, the following considerations are particularly important:

- Geographic scale, or the spatial extent of an analysis;
- Spatial resolution, or the size of grid cells analyzed;
- Temporal resolution;
- Duration of the analysis, or the number of hours or days analyzed; and
- Time of year that the analysis is conducted.

To achieve desired levels of accuracy and a reasonable match between modeled and monitored data, transportation data need to be defined at corresponding spatial and temporal levels of detail. The geographic scale of transportation-related air quality analyses is becoming larger. No longer conducted solely at the intersection- or even urban-area level, these analyses increasingly are being conducted at a multistate level of geographic scale. Monitored air quality impacts of many TCMs, though, will have their largest percentage impact and are likely to be most clearly seen at smaller geographic scales of analysis. This scale may be that of an intersection or roadway in a dimension of perhaps 3 to 10 times the facility's width.

Air quality modeling practices can be grouped by category of pollutant—those directly emitted (primary) and those formed in the atmosphere through chemical reaction (secondary).

The impact of primary pollutants may be modeled at the local scale, the urban scale, or larger regional scales. Secondary pollutants are modeled at scales from urban to regional or greater. Modeling at the local scale may be based on a Gaussian formulation, thereby taking into account dispersion for large point, line, and area sources. Grid-based modeling is employed for reactive pollutants and, in some cases, for primary pollutants. In a few areas, CO is simulated at the urban scale using a grid model, even though CO concentrations are treated as uniform over the spatial scale of the grid cell or less. Where attention is directed at several individual sources of primary pollutants, multiple-source Gaussian models may be applied.

The magnitude of the impact of implementing one or more TCMs (the signal), in most cases, is likely to be smaller than the uncertainties (the noise, composed of bias, imprecision, and "natural" variability) associated with either the concentration estimates of air quality simulation models (composed of emissions, air quality, and meteorological models) or monitored concentrations. The signal-to-noise ratio, both in the real world and in modeling, is likely to be considerably more unfavorable for secondary pollutants (ozone, NO_2, and secondary fine particles) than for primary pollutants (primary particles, CO, and NO_x).

In general, it is recommended that the impacts of instituting TCMs should be first discerned by examining changes in concentrations of primary pollutants at a local scale. Changes in secondary pollutant concentrations are anticipated to be much smaller, as well as substantially influenced by emissions from other sources. To maximize the chances of detecting a signal for a primary pollutant, the geographical area under scrutiny should be near the emissions source. In other words, one should look for change in the ambient environment immediately downwind of where the emissions change is occurring. Looking elsewhere is tantamount to reducing the signal-to-noise ratio and making it even harder to detect the signal.

The modeling and analysis of ozone distributions, nevertheless, is a high priority because of the following:

- Mobile sources contribute directly to the formation of ozone;
- Transportation and TCM strategies may be an integral component of a comprehensive strategy to reduce ozone concentrations;
- Examining the impact of emissions changes through the analysis of ambient VOC and NO_x concentrations at the local scale should be linked to the analysis of ozone concentrations at the regional scale; and
- There is a need to determine if VOC or NO_x is limiting in the formation of ozone (such knowledge being critical to establishing if control of the former or latter precursor will be more effective in achieving air quality control).

In essence, the analysis of changes in concentrations of ozone and other secondary pollutants in response to the introduction of TCMs is needed because, in most areas, no one source or source category has a dominating effect on ozone. Thus, the impacts of on-road motor vehicles constitute an important contribution to ozone when a comprehensive control plan is being developed and implemented. Moreover, it is critical to determine if VOC or NO_x control is likely to be effective in reducing ozone.

Ambient measurement can detect a change of interest. Types of ambient measurement include application of new or innovative monitoring approaches (e.g., the conduct of tracer experiments and the analysis of tracers of opportunity). The following is an approach to transportation air quality analyses that combines elements of air quality monitoring with analytical modeling:

- **Evaluate Existing Data**—Consider each project on its own terms: pollutants of interest, TCMs under consideration, relevant spatial scales, need for evaluation of model performance, availability of data, and likelihood of modeling bias or presence of compensating errors. Review and evaluate available air quality assessments for the area, such as SIP modeling and the findings of data analysis efforts. If the pollutant of interest is ozone, determine if the chemical system is VOC- or NOx-limited. Make an initial appraisal of the likely effects of TCMs on the primary pollutants of interest. To do this, conduct local scale modeling to assess expected impacts on precursor concentration levels and to evaluate the feasibility of actually observing the estimated concentration levels. If TCM effects are observable, state the goals and evaluate the merit of conducting a monitoring program. In doing so, estimate and consider costs and benefits.
- **Develop Analysis Approach**—After assessing the particular situation, develop a "most suitable analysis approach" (including data analysis and local and urban scale modeling), realizing that there may be significant limitations or problems to be surmounted. Assess whether results are likely to be of value in light of the limitations faced.
- **Conduct Monitoring**—Pursue monitoring where justified. Consider the type of observational program, costs, and duration of the efforts. Assess whether monitoring results and subsequent analyses of data can stand on their own or should serve as a basis for evaluating model performance or both.
- **Perform Modeling**—Consider the merits of conducting local, urban scale, or regional modeling. Apart from use in initial coarse estimation, consider local scale modeling only in consonance with monitoring and performance evaluation. Apply urban scale modeling in cases where the signal-to-noise ratio is favorable. If modeling is applied, uncertainties in the results should also be estimated and any appropriate qualifications on the use or value of the results should be stated.

COMPUTATIONAL ENVIRONMENT

To date, TCM air quality analyses have resulted from a piecing together of independently developed techniques, such as travel demand and emissions modeling tools. This cobbling together of existing tools has resulted in inflexible approaches to complex problems. Further, these tools have been in use for many years and have not benefited from emerging computer technologies.

With the exception of the current EPA Models3 air quality modeling initiative, existing modeling tools, although they have made use of hardware advances (faster computing, faster and larger memory, and larger hard disk storage) have not been reengineered to take advantage of parallel advances in computing software. Models are still using flat file databases without relational capabilities; ad hoc reporting and analysis are virtually nonexistent; and multiuser, distributed databases are not being employed. Using these tools, therefore, requires cumbersome data coding and recoding, sequential processing, and single function applications of complicated computer programs.

Emerging computing technologies, applied to transportation air quality analytic needs, can illuminate the synergistic effects of multiple factors affecting air quality. The following major, new, and proven computing technologies can be used to provide the computational foundation for a new transportation air quality analytical framework:

- Geo-referencing;
- Open systems architecture and shared databases;
- Client-server (and/or server-net) applications;
- Object-oriented databases, programming, and design; and
- Graphical user interface.

These computing technologies could facilitate new ways of understanding the transportation air quality interrelationship.

POTENTIAL NEAR-TERM IMPROVEMENTS

Although longer term improvements in the TCM transportation air quality analytical framework are desirable, immediate improvements based on "existing modeling technology" can be made to correct, at least partially, current analytical deficiencies. The immediate strategies that agencies can use to improve their capabilities to analyze TCMs reflect selective enhancements to the current "four-step" set of planning and analysis tools.

Figure 3 is a schematic of the current transportation analysis framework and an array of near-term enhancements that can be used to improve an agency's ability to evaluate TCMs. The focus in Figure 3 is on the transportation module, although near-term emissions modeling enhancements also are possible. Shown in the shaded column on the left-hand side of Figure 3 are the steps that constitute the current four-step transportation analysis process (i.e., trip generation, trip distribution, mode choice, and traffic assignment) and important supporting procedures (e.g., land use, vehicle ownership, and time-of-day).

The other boxes in the diagram represent areas where immediate improvements can be made to address existing deficiencies. These identified improvement areas represent topics where considerable research and development have been completed in recent years and where proven analytical techniques already exist that can be adopted by MPOs and states DOTs. Although most transportation planning organizations already have implemented at least some of these enhancements, few organizations have been able to implement a near-term travel model improvement program as comprehensive in scope as implied by Figure 3.

Each enhancement identified in Figure 3 has a number corresponding to the following potential improvements:

1. **Incorporation of Feedback Linkage**—Many of the limitations of conventional models lie in their inability to accurately reflect the "travel conditions"—as represented in the time and cost of travel—throughout the entire set of relevant travel choices. This is a particularly important concern when evaluating measures that may induce changes in behavior (from locational decisions all the way through mode, route, destination and time-of-day choices for a particular trip). It is valuable to have this linkage occur among the steps of trip distribution, mode choice, time-of-day and assignment (primary link), and yields even more realism (and impact) if the link is extended back to the land use, household vehicle ownership, and the trip generation steps.

   - **Individual Model Enhancements**—Each step in the conventional modeling process has weaknesses relating to the evaluation of TCMs. Any of the following areas can be enhanced:

- **Land Use/Activity Forecasts**—Most areas cannot assess changes that might occur in the location patterns of households and employment activity in response to changes in transportation conditions (e.g., infrastructure, congestion, and pricing). Potential enhancements include adaptation of formal land use models or guidance on the use of submodels that offer insight into household/business response to various policy changes.
- **Vehicle Ownership**—Enhancement alternatives include upgraded, more fully specified and policy-sensitive vehicle ownership and choice models that can simulate household response to vehicle-related policies affecting the number or type of vehicles owned.
- **Trip Generation and Distribution**—Enhancement alternatives include upgraded, more sensitive trip generation models, as well as possible submodels to handle nonmotorized trips, telecommuting, and alternative work schedules.
- **Mode Choice**—Enhancement alternatives include upgraded models with the capacity to include more alternatives (e.g., HOV), an improved specification (in terms of variables and policy sensitivity), a more accurate choice structure, or use of submodels to handle bike/walk alternatives or other specialized modal concepts.
- **Time-of-Day**—Enhancements can be introduced in the form of either time-of-day choice submodels or peak spreading techniques.
- **Route Choice**—Current traffic assignment models do not readily account for the impacts of toll roads or allow for route choice response by travelers. There are procedures that allow for more realistic handling of roadway toll issues, and submodels offer a possibility for handling complex travel behavior.

2. **Sources for Models, Model Parameters, and Data**—The enhancements characterized above raise questions as to whether all of these procedures must be developed uniquely by each site. The following are potential options:

   - **Borrowed Models**—Not all sites may be in a position to develop their own models from scratch. One possibility is that models in use elsewhere could be transferred from another urban area, either as an interim or as a permanent solution. This includes model structures, estimated coefficients for important model parameters, and elasticities derived from either modeling analyses or empirical evaluations.
   - **Survey Data**—If a site wishes to develop or adapt a model, it can call on several sources. The 1990 Census and 1990 National Personal Transportation Survey (NPTS) are important potential sources of transportation data. Many metropolitan areas also have conducted recent household travel surveys.
   - **Stated-Preference Surveys**—Stated preference surveys, although not yet in widespread use within the transportation profession, are extensively used by the market research discipline as a way to gain insight into choice behavior in relation to alternatives for which solid empirical information does not exist. In recent years, stated-preference surveys increasingly have been used in the evaluation of innovative forms of TCMs, alternatively fueled vehicles, and market-based pricing incentives. In a stated-preference approach, statistical estimates of "tradeoff" rates among the attributes of various alternatives are derived by having a respondent systematically choose from among potential options in a way that indicates the relative importance of key attributes.

3. **Household Sample Enumeration**—If an agency introduces some or all of the changes described above, the conventional four-step travel demand model system can be used for air quality purposes with greater capability and confidence. In effect, the described enhancements incrementally improve the capability of each module. These enhancements, however, do not correct a more basic limitation in the inherently aggregate four-step process—that it does not fully retain what is happening at the household level, particularly in relation to household interactions and socioeconomic differences. In sample enumeration, as discussed previously, data representative of a sample of households rather than average conditions of a TAZ are used as the basis for simulating a response to a transportation measure. Individual household results, then, are related back to the population and the transportation system as a whole through sample expansion techniques. This method has been used with success either as a substitute for or a supplement to the existing four-step travel modeling process.

4. **Traffic Simulation**—The outputs of a traffic assignment do not fully reflect key operational variations that may be important to emissions (e.g., queuing and delay patterns on links, and speed/acceleration profiles) and that are much more relevant to emissions than average speed. The linking of traffic microsimulation with conventional travel demand models is being researched as a way to improve the realism of the transportation inputs that reflect these stop-and-go patterns. Microscopic traffic simulation models simulate the movement of individual vehicles and include programs such as FRESIM and NETSIM (this type of simulation is also being incorporated in the TRANSIMS work being performed by the Los Alamos National Laboratory.) Macroscopic traffic simulation is based on higher level deterministic relationships and takes place on a highway section-by-section basis rather than by tracking individual vehicles. Examples include CORFLO and TRANSYT-7F.
Coverage and Precision of Travel Networks—Coded network descriptions of highway and transit facilities and services are used in the assignment step and form the basis for calculating travel times, estimating levels of service, and producing other performance indicators. The level of detail in which networks are described varies greatly as to the types of facilities represented (in particular, the number of arterials and major collectors included) and the treatment of special network features such as HOV lanes, ramp meters, and intersection movements. The representation of link speed and capacity also varies greatly—particularly in the number of capacity classifications and range of speed-volume relationships included.

Improved modeling accuracy for TCMs can be achieved by including more facilities in the highway network (e.g., minor arterials and significant collectors); explicit coding of special network features (e.g., HOV lanes, ramp meters, and intersection details) and use of more capacity classifications and a wider range of speed-volume relationships. In addition, separate rail transit and bus transit networks are being coded—each with considerable detail describing access modes (and in some cases, extending to separate networks specifically depicting the transit access options). Such network detail may be needed to support nested logit mode choice models.

5. **Emissions and Air Quality**—Among the options available for immediate implementation are three improvements that can be made relatively easily to existing emission factor models to increase their accuracy. These options are to

- **Include Operating Mode Corrections**—The condition (i.e., cold start, hot start, or stabilized) under which a vehicle is operating has a significant impact on vehicle exhaust emissions, and the implementation of TCMs often affects the existing operating mode mix. For example, the implementation of a park-and-ride lot may not eliminate a trip but could decrease its length. Thus, vehicles may never get out of the cold-start mode of operation. Unless, MOBILE is configured to account for this effect, the emissions benefit of this TCM will not be correctly quantified.
- **Develop Trip-based Emissions Estimates**—MOBILE5 accounts for start emissions in the operating mode fractions. One approach to aid the quantification of the emissions impact of TCMs is to separate the start emissions from the running exhaust emissions contained in the MOBILE model by calculating two separate quantities for a vehicle trip: stabilized operating emissions and a cold-start offset.
- **Link Travel Mode to Vehicle Class**—Both MOBILE and EMFAC track emission estimates for separate vehicle categories (e.g., cars, light-duty trucks, heavy-duty trucks, and motorcycles). Given the large differences in emission rates between vehicle categories, it is important to quantify the distribution of travel among the vehicle categories correctly. Methods have been developed to translate the vehicle classification system typically used for highway traffic counts to the EPA vehicle classification scheme. This translation helps to create locality-specific vehicle mix estimates by facility type.

Existing transportation air quality analytical capabilities also can be easily enhanced through the use of post processors and other similar off-line methods. The Post Processor for Air Quality (PPAQ), developed by Garmen Associates, is one example of a widely used post processor. PPAQ accepts as input the highway link physical attributes and assigned traffic volumes produced by the four-step travel demand model. PPAQ then performs a complex process of computing and adjusting time-period volumes; calculating link and signalized intersection capacities, speeds, and delays; and accumulating VMT and average speeds. The system prepares inputs to and runs the MOBILE model to calculate emissions. Output databases are prepared consisting of VMT, speeds, and emissions. These are summarized by link, area, facility type, and time period. A suite of report generation and support utilities are provided in the system.

A key feature of PPAQ is that it integrates traffic analysis, emissions modeling, and reporting steps in one job stream. This greatly simplifies the actual execution of robust emissions analyses in conjunction with transportation models. PPAQ allows the user extensive control over capacity and speed relationships and coefficients, aggregation techniques and schemes, adjustments to link volumes and VMT totals, time-of-day relationships and vehicle-type mixes, and myriad other details that constitute an emissions analysis.

CONCLUSIONS

The basic outline of the framework recommended for the analysis of air quality and other benefits and costs of air quality transportation control strategies is intentionally broad in scope. Numerous improvements to current analysis methodologies can be immediately implemented that will improve the accuracy of estimated transportation and emissions impacts. Critical shortcomings, unfortunately, will still remain. Deficiencies in the variables used to link transportation, emissions, and air quality analyses are especially important if accurate estimates of spatially and temporally distributed emission impacts are to be produced. The long-term need is for a fundamentally new set of analytical capabilities rather than just incremental improvements to current modeling approaches. These longer run improvements require a combination of improved analytical methodologies and better data. Equally important, this new generation of transportation air quality analytical capabilities should take advantage of emerging computational environments.

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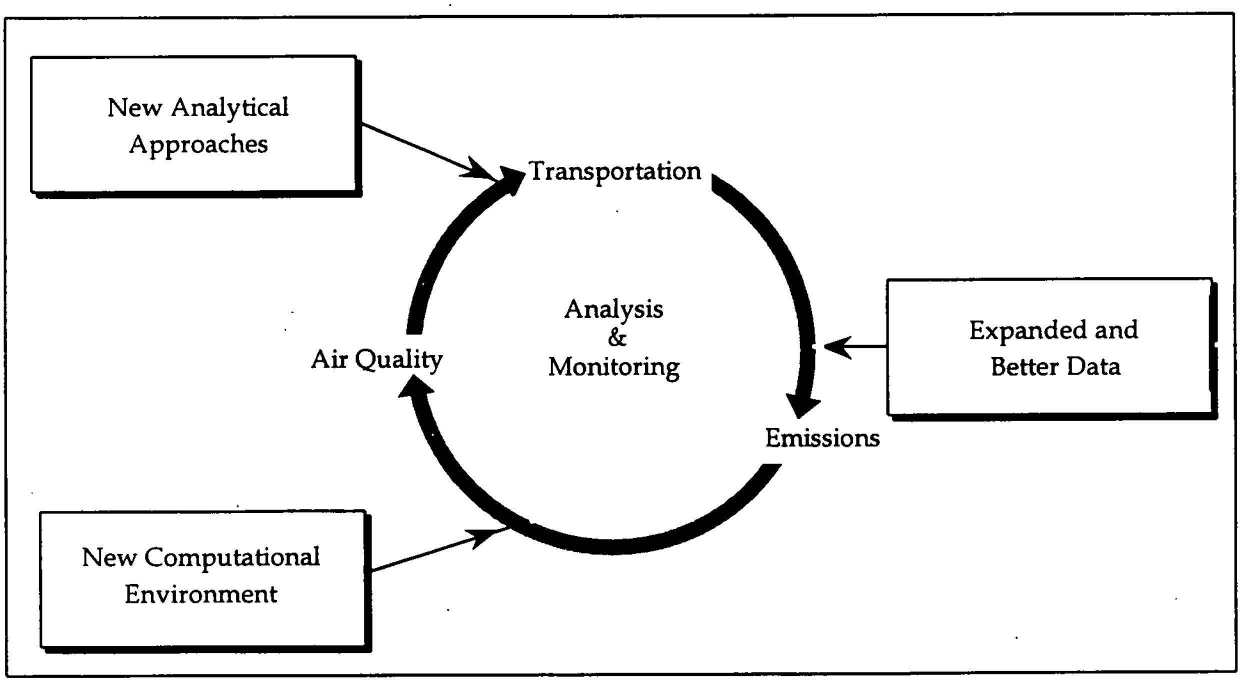

Figure 1. Components of an improved TCM analytical framework.

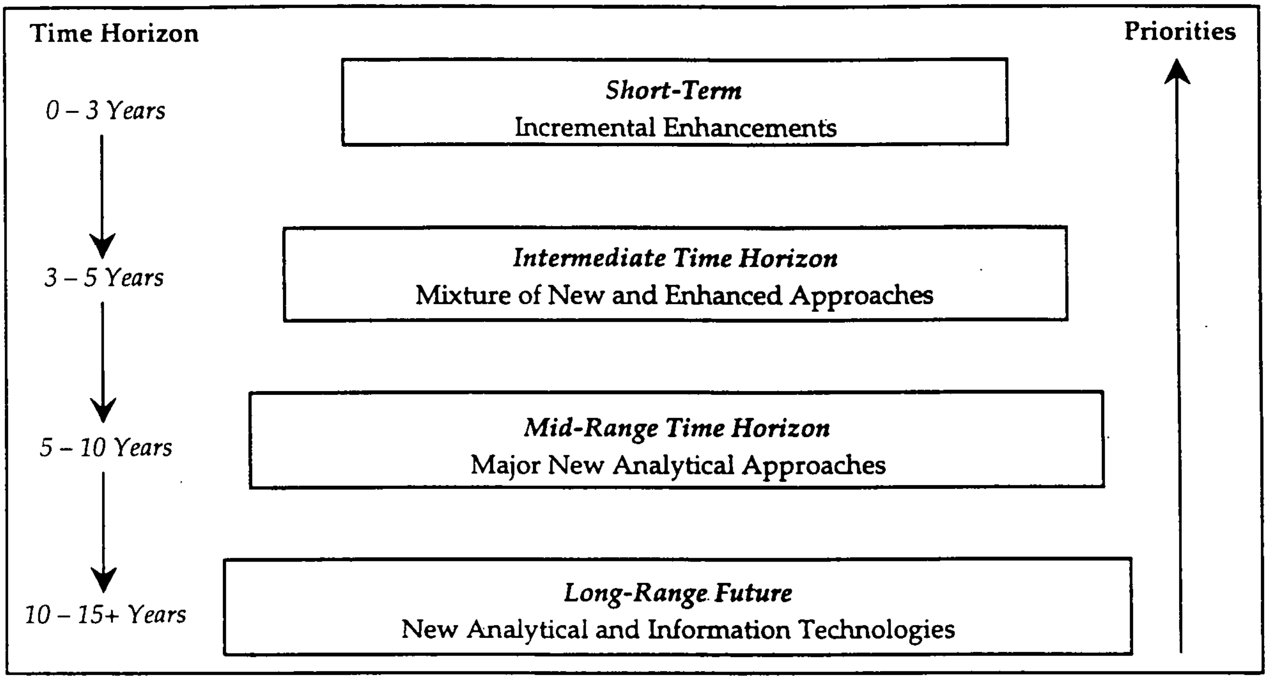

Figure 2. Time horizons for development of a new TCM analytical framework.

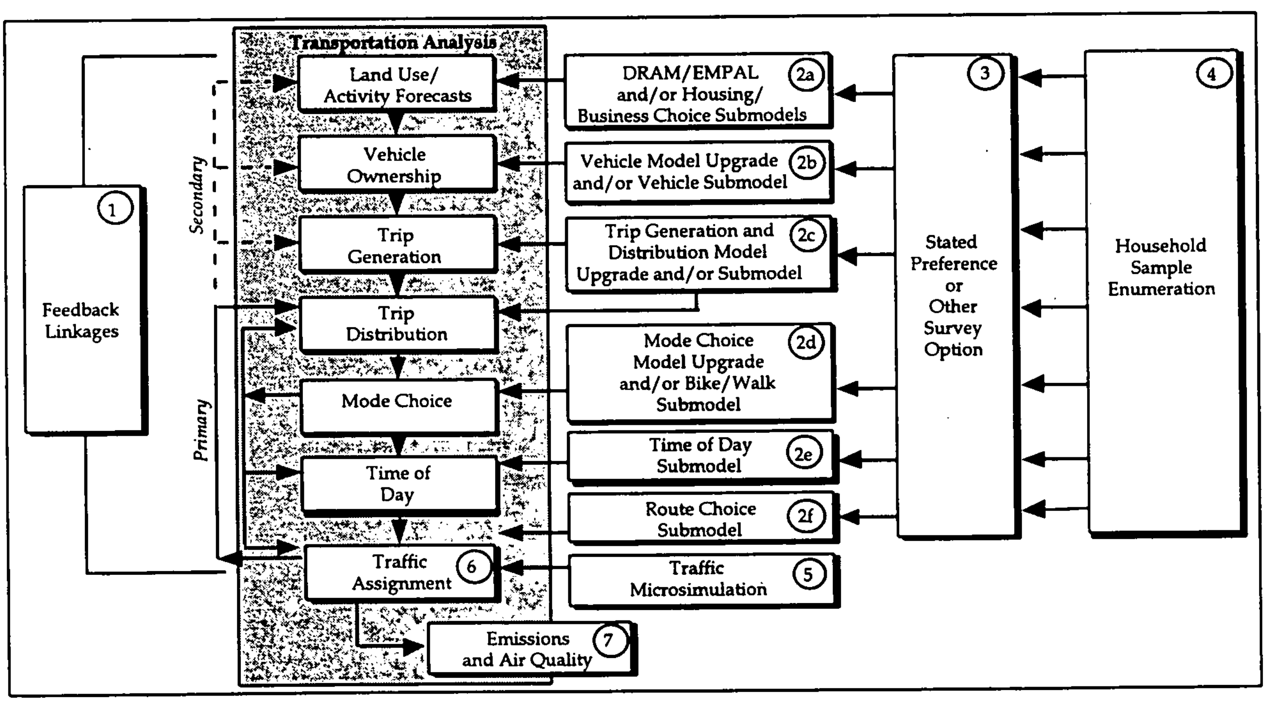

Figure 3. Overview of potential near-term enhancements to current transportation analytical framework.

TABLE 1 Prioritized listing of data required for modeling TCM emission impacts

	VOC	CO	NO_X	PM
1.	Vehicle miles traveled	Vehicle miles traveled	Vehicle miles traveled	Vehicle miles traveled
2.	Fraction of cold/hot starts	Fraction of cold/hot starts	Heavy-duty diesel	Road surface silt loading
3.	Ambient temperatures	Ambient temperature	Speed/acceleration/driving profile	Travel by vehicle class
4.	Time/location of starts	Time/location of starts	Grade/terrain	Travel by facility type
5.	Speed/acceleration/driving profile	Speed/acceleration/driving profile	I/M characteristics	Vehicle weight
6.	Fuel characteristics	I/M characteristics	Travel by vehicle class, time of day	Heavy-duty diesel travel
7.	I/M characteristics	Non-normal travel, e.g., special events/ accidents	Travel by vehicle class, facility type	
8.	Travel by vehicle class, time of day	Travel by vehicle class, time of day	Bus and rail transit travel	
9.	Travel by vehicle class, facility type	Travel by vehicle class, facility type	Single occupant vehicle rates	
10.	Hourly temperature distribution	Hourly temperature distribution	Ramp activities	
11.	Average trip length	Average trip length	Vehicle load and A/C use for light and heavy-duty vehicles	
12.	Single occupant vehicle rates	Single occupant vehicle rates	Non-normal travel, e.g., special events/accidents	
13.	Bus and rail transit travel	Bus and rail transit travel	Freight mode choice (truck vs. rail haul)	
14.	Trip ends with hot soaks	Grade/terrain		
15.	Locations of diurnals	Ramp activities		
16.	Ramp activities			
17.	Non-normal travel, e.g., special events/ accidents			

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