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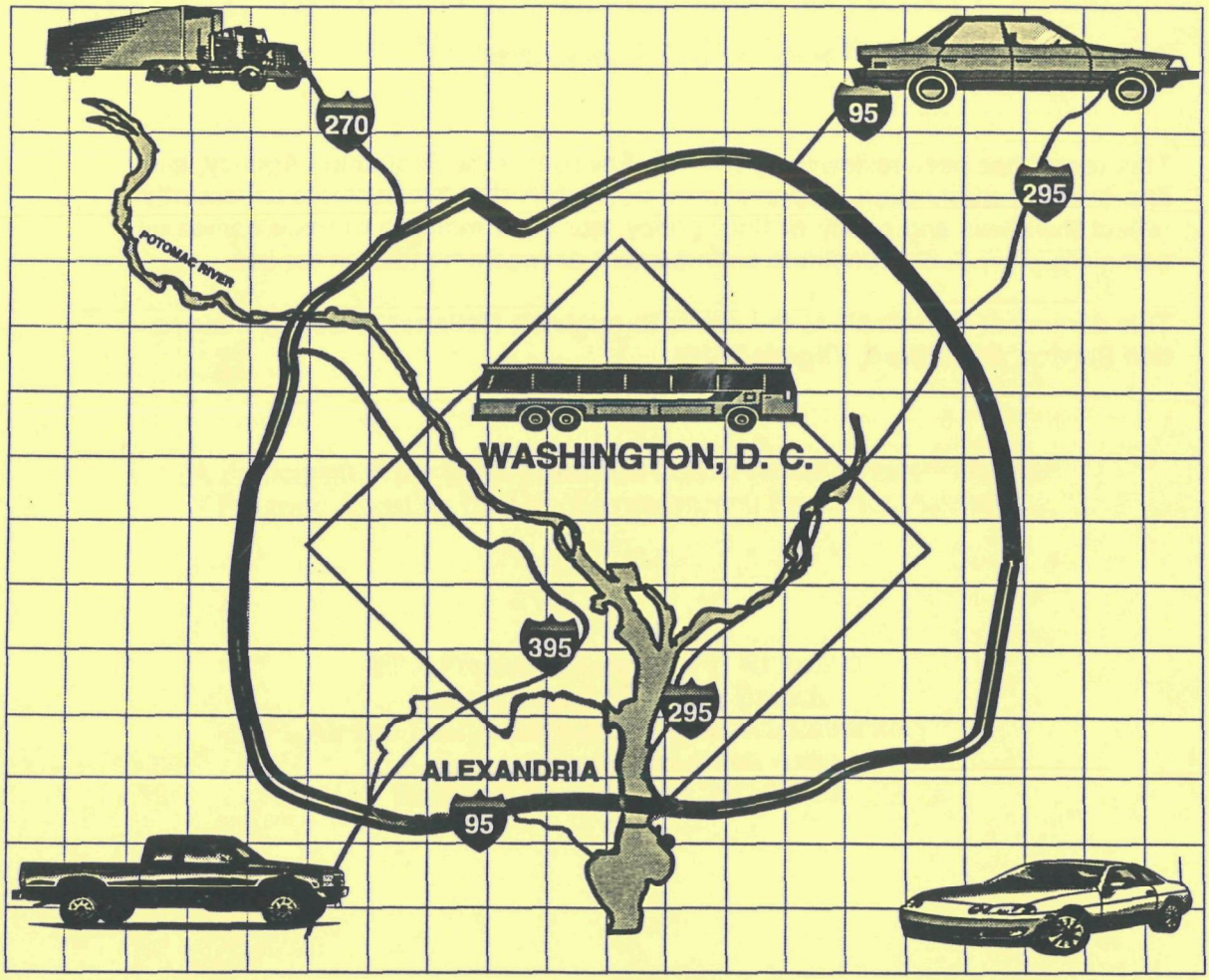
EPA Conceptual Designs For A New Highway Vehicle Emissions Estimation Methodology



JEIOG

Joint Emissions Inventory Oversight Group

Prepared for Office of Air Quality Planning and Standards

Prepared by Air and Energy Engineering Research Laboratory

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CONCEPTUAL DESIGNS FOR A NEW HIGHWAY VEHICLE EMISSIONS ESTIMATION METHODOLOGY

by

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ABSTRACT

This report discusses six conceptual designs for a new highway vehicle emissions estimation methodology and summarizes the recommendations of each design for improving the emissions and activity factors in the emissions estimation process. The complete design reports are included as appendices. EPA asked six contractors to assist in developing ideas for a potential methodology to estimate highway vehicle emissions that could be developed for use in 5 to 10 years. They were selected because of their experience in working with mobile source emissions inventories.

In general, the contractors suggest developing new modules within the emission estimation process to provide users with more detailed information on the causes of vehicle emissions. The essence of these concepts is the need for more comprehensive integration of data between the transportation planning model and the emission factor model.

The individual reports did reinforce comments voiced by other experts for modal data and more responsive transportation models, though they did not identify totally new concepts not already being considered by EPA research programs.

This report covers a period from March 1991 to July 1991. The work was completed as of September 1991.

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SECTION 1
INTRODUCTION

In April, 1991 six tasks were awarded to look for new concepts that could potentially provide improved emission inventory estimates from highway vehicles in 5 to 10 years. This project was a follow-on to the two highway vehicle workshops held in the summer of 1990 to solicit research recommendations from emission inventory experts. (Wilson, 1991). The contractors,

- Alliance Technologies Corporation (TRC)
- Desert Research Institute
- E.H. Pechan & Associates, Inc.
- Radian Corporation
- Sierra Research, Inc.
- Systems Applications International

were selected because of their experience in using and developing mobile source emission inventories for EPA and California. E.H. Pechan & Associates teamed with COMSIS Corporation to address transportation modeling recommendations. Guidelines provided to the contractors in March 1991 included:

Problem Definition

> Emission inventory estimates are used by EPA and states in models to determine the effectiveness of various control strategies for achieving air quality standards. ....Methods available today for estimating emissions from highway vehicles may not be adequate for the new fuels, technologies, and transportation control methods available 5 to 10 years from now. This project is intended to begin the process of looking for an optimum methodology.

Background

> Analyses of the SCAQS [South California Air Quality Study] tunnel study data indicated that emission inventory estimates for urban areas using the EPA MOBILE(3-4) or EMFAC7(C-E) emission factor models could be much lower than actual. All highway vehicle emission estimates of NMHC, NOx, and CO for ozone and CO SIP non-attainment areas used these models through 1987 [MOBILE5 and EMFAC7F have been available since 1991]. Since CO, NMHC, and NOx from highway vehicles are already such a large portion of an urban areas estimated emissions, a large potential increase from this source could force

significant changes to control strategies that were designed to achieve ambient standards.

EPA conducted two workshops in 1990 for various experts to brainstorm about state-of-art improvements that could be made in estimating emissions from highway vehicles....Some design concerns were noted:

- Any new procedures must be validated against a "ground truth."...
- The uncertainty of data estimates must be defined and reduced.
- New procedures must be affordable by all SIP areas...
- New procedures must be sensitive to changes in vehicles, fuels, and transportation control measure (TCM's) approaches as well as meeting data requirements of atmospheric photochemical models.
- Current emission estimation methods rely on parameters (e.g.; VMT, speeds, I&M effectiveness) that are derived from models and cannot be satisfactorily validated. [The AWMA paper by] Leonard Seitz ... proposed that emissions are nearly constant for varied speeds over time. If this is a reasonable assumption, our future model might concentrate on those conditions causing emissions to exceed this norm rather than emphasizing understanding emissions vs. speed.
- High tech scientific developments such as GIS and satellite (or other remote sensing) data should be considered in new designs.

Studies are being planned and conducted by California and EPA to evaluate vehicle utilization, driving patterns, emissions as related to vehicle load and speed, I&M program effectiveness, and VMT projections. Plans have been made to improve data through modal analyses and computer simulations of emissions as related to vehicle load and operation.

Program Objective

A focal point is desireable to orient and coordinate research efforts to ensure that optimum procedures are available in 5 to 10 years. The results of this work assignment will provide (in the opinion of the contractor) the optimum method for estimating emissions from highway vehicles. The time frame for implementing the new method is 5 - 10 years.

Because of the special strengths resident with the different contractors, it is expected that the ultimate optimum approach will be a combination of ideas from each of the different designs. EPA will establish a working group of Federal, State, and private experts to evaluate these conceptual designs and suggest a consolidated methodology design that best meets the needs of all users.

This report summarizes the conceptual designs from the six contractors. Their complete reports are included in the Appendices. In general, the contractors believe that the current model (MOBILE4) provides overly aggregated results and they suggest developing new modules within the emission estimation process to provide users with more detailed information on the causes of vehicle emissions. The essence of these conceptual designs is the need for more comprehensive integration of data between the transportation planning model and the emission factor model. To

present the contractors' recommendations clearly and to avoid redundancy, this report combines their concepts and organizes them according to topic, rather than simply summarizing each contractor's conceptual design in a list. First, concepts for improving emissions factors will be considered, followed by recommendations for improving activity factors, and finally ideas for organizing and coordinating the new emission and transportation models.

The current approach used by EPA to provide emission estimation procedures is to continually incorporate new findings as incremental changes to the existing methodology. A weakness of this approach is that with the advent of major technology changes in pollution controls, polluting equipment, measurement devices, and analytical tools EPA could miss cost effective improvement opportunities by considering only the incremental approach. The Joint Emissions Oversight Group (JEIOG), established by EPA in 1991, provided guidance to the Office of Research and Development to conduct research to find and develop potential quantum leap improvements to the emission inventory process that could be implemented in the future.

As EPA develops its research program to prepare emission inventory models for the future, it is attempting to make sure that no new promising concepts are overlooked. The request to the six contractors for concepts was an initial step in this process. For the most part, the reports did not identify any totally new concepts not already being considering by EPA research programs. Most of the ideas were linked to existing procedures, requiring extensive data collection concerning vehicle emissions and operations on highway networks. The reports did reinforce comments voiced by other experts for modal data and more responsive transportation models. Where concepts, such as modal modeling, can be shown to be affordable and provide more accurate estimates, future models will attempt to incorporate them. EPA research to evaluate the most promising concepts and validate algorithms for them is planned through 1996.

SECTION 2
RECOMMENDATIONS FOR IMPROVING THE EMISSION FACTOR MODEL

The primary improvement to the emission factor model which all the contractors recommend is to begin measuring the emissions produced during the four modes of vehicle operation: acceleration, deceleration, cruise, and idle. This would be in addition to the emission measurements for cold and warm starts and for the different vehicle speeds. Vehicles emit significantly different levels of pollutants during each mode of operation and, as a result, this additional information is essential for accurate emissions estimates. The quantification of such data will in turn require transportation models to include information as to where these modes occur within the travel area. A more complete discussion of this will be covered later in the report.

The collection of modal data (i.e. data concerning various engine operating modes such as idle, cruise, or acceleration) dictates that, for emissions inventory improvements, modifications must be made in the current FTP cycle to incorporate the new information. Indeed, most of the contractors suggest discarding the FTP cycle for emission factor development in favor of some alternative "in-use" test. For instance, if the nominal FTP driving cycle is replaced with vehicle operating mode distributions, Systems Applications International (SAI) believes that factors specific to vehicle operating mode will be needed in order to unambiguously establish the mode a vehicle is in and how the emissions vary by mode. Consequently, driving-cycle-based emission factors would be obsolete. The primary input for this model would be factors such as: (1) basic mode (e.g., cruise or creep); (2) speed; (3) acceleration; (4) engine state; and (5) canister loading. While the contractors' suggestions for gathering the data differ, their idea that information concerning vehicle operating mode must be included in the emission factor model remains constant.

Most of the contractors also recommend including local information in the emission factor model such as super-emitting vehicles, alternative fuels, and fluctuations in temperature from morning to evening. Sierra Research's (hereafter Sierra) conceptual design calls for the development of "engine maps" to represent the mix of vehicles operating in an area. Engine maps would characterize emissions as a function of speed and load for a set of vehicles including factors for input such as: (1) the mix of fuel and emission control devices used in previous vehicle models

along with a projection of the mix for future models; (2) the default distribution of vehicle categories and model year registrations within each category; and (3) the effect local I/M programs have on the mechanical condition of vehicles and, in turn, the effect they have on emissions reductions. Desert Research Institute (DRI) advocates the input of diurnal temperature variations into the calculation of emission rates and a flexible system of allocating emissions to locations.

The contractors also recommend determining the percentage of vehicles emitting in the super, very high/high, and normal modes and considering their effect on emissions. Sierra suggests that the sampling for performing in-use emission tests be designed to effectively capture emission rates, the fraction of vehicles and their travel in each of the emitting modes, and the reasons for emission control failures when they occur. The contractor concludes that this type of data collection makes it possible to more accurately estimate base year emissions, as well as estimate the effect of future control regimes on future year emissions.

Several contractors also suggest including more extensive data concerning stationary vehicle evaporative emissions in the calculation of emission rates. These include diurnal, hot soak and resting evaporative losses as well as cold and hot start exhaust emissions. Radian Corporation's methodology, named EVAP 2.0, calculates evaporative emissions on an hour-by-hour basis, as opposed to the procedures used in existing models which calculate emissions on a daily basis and assume emissions are evenly speed throughout the day. Radian believes that the methods used in MOBILE4 do not permit proper spatial allocation of these emissions, since they are calculated on a grams per mile basis and spread over the road network. Radian concludes that their method will permit proper spatial allocation of both exhaust and evaporative emissions since they will each be calculated separately. In this way, it will be possible to allocate the emissions closer to where they occur.

DRI suggests a rather different methodology for the emissions measuring process. DRI suggests deriving empirical on-road estimates of emissions using remote sensing; rather than extrapolating data from dynamometer tests. The method includes freeze-frame video images of vehicle license plates. The ratio of visible light transmission to CO_2 can then be related to the grams of pollutant emitted per gallon of fuel consumed. DRI believes that with reasonable assumptions about vehicle mileage, this can relate emissions to VMT. In this way, an empirical model of pollutant emissions per VMT can be determined for different types of roadways, driving conditions, and times of day.

SECTION 3
RECOMMENDATIONS FOR IMPROVING THE ACTIVITY FACTOR MODEL

As mentioned earlier, the collection of modal data for the emission factor model will in turn require the development of more comprehensive activity factors. The contractors deal with this problem either by expanding the current transportation model to include not only VMT but information on roadway type and time of day or by eliminating VMT altogether in favor of listing vehicle operating mode distributions by area and time. PECHAN/COMSIS's conceptual design represents the first of these two views. PECHAN/COMSIS recommends adding three new models to the travel demand modeling process. First, a model to estimate the percentage of vehicle travel occurring in the various operating modes. The model would provide percentage estimates of daily VMT in each of the four operating modes of acceleration, deceleration, cruise, and idle. The model would be calibrated based on new data that need to be collected relating vehicle operating mode to variables such as: (1) the types of facilities (e.g., freeway, arterial) over which each vehicle trip is made; (2) the volume/capacity ratio of the facility; (3) the time of day (peak and off-peak); and (4) information as to traffic control density (e.g., X traffic signals per mile). PECHAN/COMSIS believes that these data can be collected through instrumented vehicle trips over a variety of urban areas. The second model seeks to estimate the fraction of vehicle trips which have cold start and hot soak emissions listed as a function of trip purpose and trip duration. The output of this model would be the number of vehicle trip ends in each traffic analysis zone (TAZ) which are estimated to have cold starts and hot soaks for both peak and off-peak periods. The third model would estimate the trip reduction effects of the various transportation control measures (TCMs) which urban areas are likely to implement. The output of this model would be the number of work purpose person trips for each TAZ-to-TAZ movement which are forecast to utilize mass transit, carpools, or drive alone measures. PECHAN/COMSIS also recommends expanding the travel demand model to cover vehicle trips and VMT for areas outside the urban cordon.

SAI represents the opposing view where VMT is abandoned in favor of empirical vehicle operating mode distributions. Under their conceptual design the actual effects of local factors and conditions on vehicle operating modes are addressed. SAI's method calls for the collection of comprehensive data on vehicle operations within an urban area. Principal reliance would be placed on the use of time-lapse aerial photography and computer image processing and analysis to

determine, by roadway or sub region, such parameters as: (1) the number of vehicles in operation; (2) the distribution of vehicle speeds by road type; (3) the distribution of acceleration by speed and road type; (4) the number of vehicles in non-free flow conditions (queued and creeping, and idling); and (5) the number of trips started and ended. SAI believes that by basing the distribution of vehicle operating modes on data for the study area, the potential bias introduced by the nonrepresentational FTP driving cycle can be prevented. Similarly, by using actual observed speed distributions on links, SAI contends that the arbitrary assignment of single average speed to each link is avoided, as is the reliance on overly simplistic speed versus volume/capacity ratio relationships such as the BPR curve and the simplistic treatment of off-network travel as having a constant speed. Some examples of the factors which effect vehicle operating mode are: lane width, road surface condition, distractions (road signs, commercial driveways and parking, on street parking, etc.), hills, and the level of aggressiveness of drivers. SAI concludes that empirical mathematical descriptions can be generated to show the variations in vehicle operating mode for an area and time. According to SAI, even though VMT is left out of the transportation picture in terms of the initial emissions estimations, the information gathered by it will later be necessary for forecasting purposes (this will be described in more detail later).

Radian Corporation also recommends abandoning VMT in its travel demand model since transportation modeling systems which incorporate VMT cannot efficiently handle variations in link-level traffic operations during peak congested conditions. Instead of using VMT, their model computes vehicle hours traveled (VHT) for each link. Correspondingly, the emission factor model will measure emission rates on a grams/hr basis, rather than grams/mi.

SECTION 4
IMPROVEMENTS IN EMISSION INVENTORY MODELING AND INTEGRATION TECHNIQUES

While the recommendations for improving the emission and activity factor models through increased collection and analysis of empirical data will be important and useful for developing more precise emission estimates in the future, the primary goal for the contractors was to present a conceptual design for a new highway vehicle emissions estimation methodology. With one exception, the contractors attempt to achieve this goal by supplementing the general emission inventory process (Figure 1) with pertinent new models to facilitate more accurate, efficient and integrated emission estimates. Generally, these contractors attempt to rectify the limitations in the contemporary four step travel forecasting process by expanding the activity factor database and adjusting the current models to account for the factors which produce these limitations. Likewise, the contractors employ similar means to improve the emissions factor model. The conceptual designs differ, however, on the type of additional data which will produce better estimates and the manner with which to integrate that data into the emission and activity factor models.

PECHAN/COMSIS's conceptual design (Figure 2), for example, mimics the current inventory estimation process almost exactly; except for the addition of three new models to supplement the travel forecasting process. Two of the models, a "Vehicle Operating Mode Model" and a "Cold Start/Hot Soak Model", would be calculated off-line incorporating data from the current travel demand model and then integrated into the emission factor model. The "Vehicle Operating Mode Model" would be combined with the collection and analysis of emission data by mode in the emission factor model to produce daily emission profiles (Figure 3). The objective is to create the smallest number of profiles possible to accurately cover the variety of trip-making that occurs in an area. The third model, a "Transportation Control Measure (TCM) Impact Model", would be directly integrated into the travel demand model (TDM), or more specifically into the mode choice module of the current TDM, rather than using it off-line as it currently is.

PECHAN/COMSIS suggests that one of the advantages of this model design is its ability to encompass the full range of vehicle operating conditions, in addition to its ability to present data at the level of detail necessary to validate and verify results. They add that until remote sensing

proves to be a practical tool for validating emission estimates, the best tool for emission modeling in a three to five year time frame would be improving I/M program performance and taking advantage of the annual data tracking possibilities. Lastly, they suggest using satellite photos for noting whether episode day conditions differ significantly from "average daily traffic."

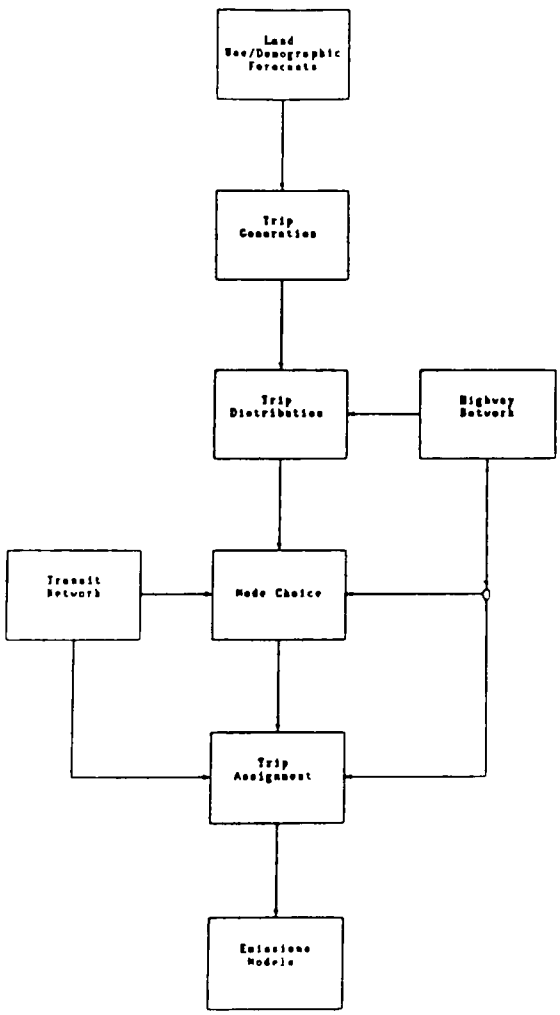

Figure 1. Conventional Urban Travel Forecasting Process (Appendix C, page C-7)

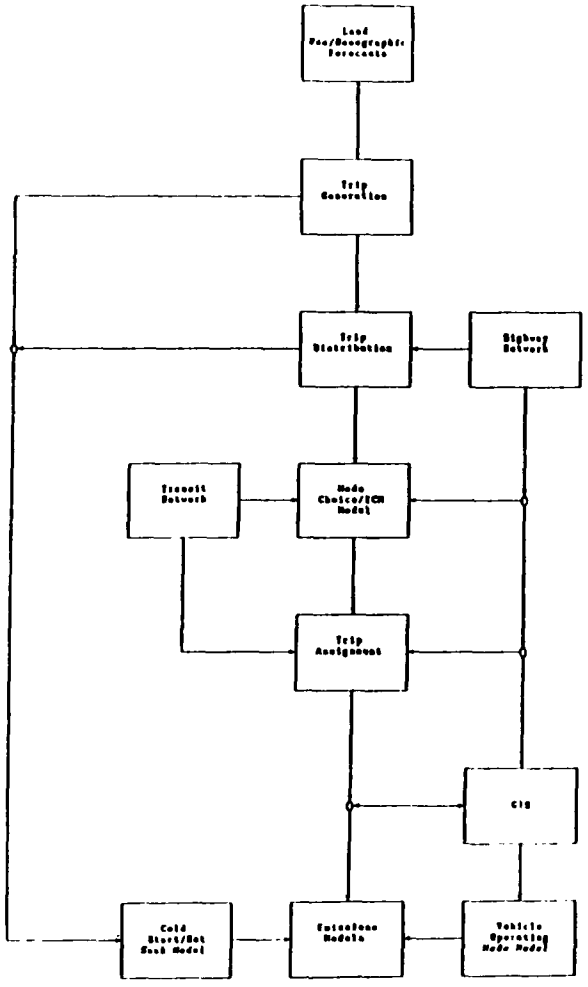

Figure 2. COMSIS Conceptual Design
(Appendix C, page C-17)

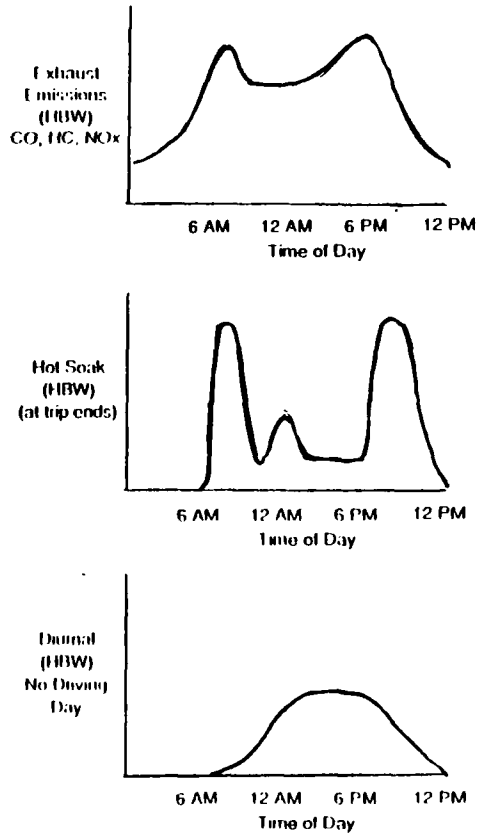

Figure 3. Example Daily Emission Profiles
(Appendix C, page C-13)

Sierra Research's modeling system (Figure 4) also closely resembles the current method employed, except they abandon the use of a single drive cycle with correction factors to account for the effects of local driving conditions. Sierra's conceptual design calls for the construction of separate emission factor estimates for each link on unique trip routes. They believe that this could be achieved by modifying current transportation planning models to supply additional information on: (1) trip length; (2) mix of roads (i.e. facility types); and (3) the congestion encountered on routes between each origin and destination (OD) zone. Also, by using local transportation surveys or other improvements, similar information would be developed for the travel that occurs within each traffic analysis zone (TAZ).

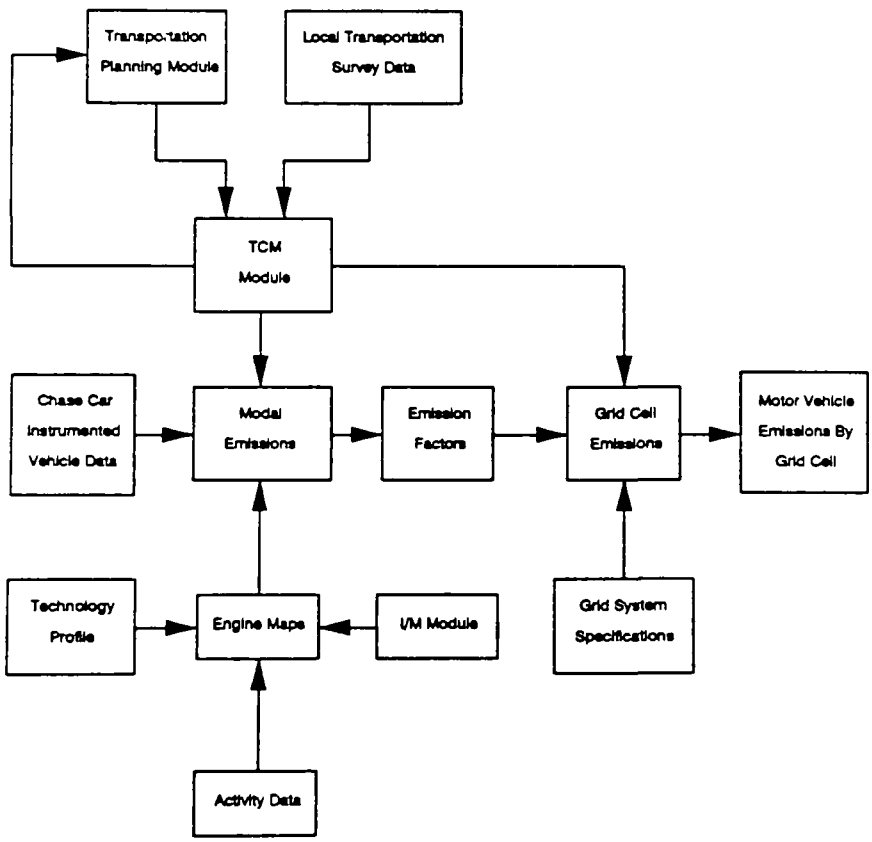

Figure 4. Sierra's Suggested Modeling System (Appendix E, page E-5)

According to Sierra, a TCM module would receive the preliminary outputs of the transportation planning module and local trip surveys to evaluate the effects of alternative TCM's on the travel-related determinants of vehicle emissions (i.e. the relationship between vehicle trips, trip length and congestion levels). This information would then be fed back to the transportation planning module to reevaluate the level of travel produced.

Sierra's transportation planning module would provide two outputs. The first output includes information on trip type, trip length, mix of roads, and congestion encountered on routes between each OD zone and within each TAZ. All this would then be input for the modal emissions module (MEM). The MEM would include this route-specific travel information, EPA drive cycle studies (includes operating conditions like speed and acceleration found on similar roads under similar congestion levels), and data from engine maps. The MEM output would be a specific emission factor for each link encountered on each trip. The second transportation planning module output would be the actual number of vehicle trips between zones and within zones. This information is later input for a grid cell emissions (GCE) module. The GCE module integrates the data from the road network and TAZ's with the link-specific emission factor estimates for each OD pair and the number of trips between each OD pair. A similar computation would be used to estimate the emissions within each TAZ. Finally, the GCE module aggregates the link and TAZ emission estimates into the grid cells a user specifies.

Sierra suggests collecting an extensive number of ground counts for an urban area that has a state-of-the-art transportation planning model with a 1990 or later base year travel estimate for the validation of travel estimates. The travel model can then be updated to reflect the road network in place at the time the ground counts were collected. The model can be validated with the normal level of ground count information. The results can then be compared with estimates that are based on the more extensive ground count survey to determine the level of accuracy the model has in representing travel throughout the urban area. Sierra additionally suggests the validation of MEM estimates through dynamometer-based measurements of emissions on the same drive cycle. Also, the information EPA and ARB develop through VEHSIME and EMFAC/BURDEN may provide a basis to evaluate the accuracy of the MEM.

Sierra notes that additional funds will be needed to: (1) develop methods to quantify the travel occurring within TAZ's; (2) modify or replace the existing models to incorporate the new methodologies; (3) expand the network to include more information about local roads; (4) determine the mix of engine maps needed to characterize new vehicle emissions; (5) translate existing I/M program modeling efforts from an FTP-based emission factor methodology to one that

uses modal emissions; and (6) analyze the data collected in the EPA and ARB chase car and instrumented vehicle surveys.

Desert Research Institute's conceptual design consists of an Emissions Modeling System (EMS) capable of accessing activity data bases from a multitude of information gathering agencies (Figure 5). Such an EMS then combines this information with meteorological data and validated emissions/activity relationships (i.e. emissions factors) to provide emissions rates for any selection of location, time, or sources.

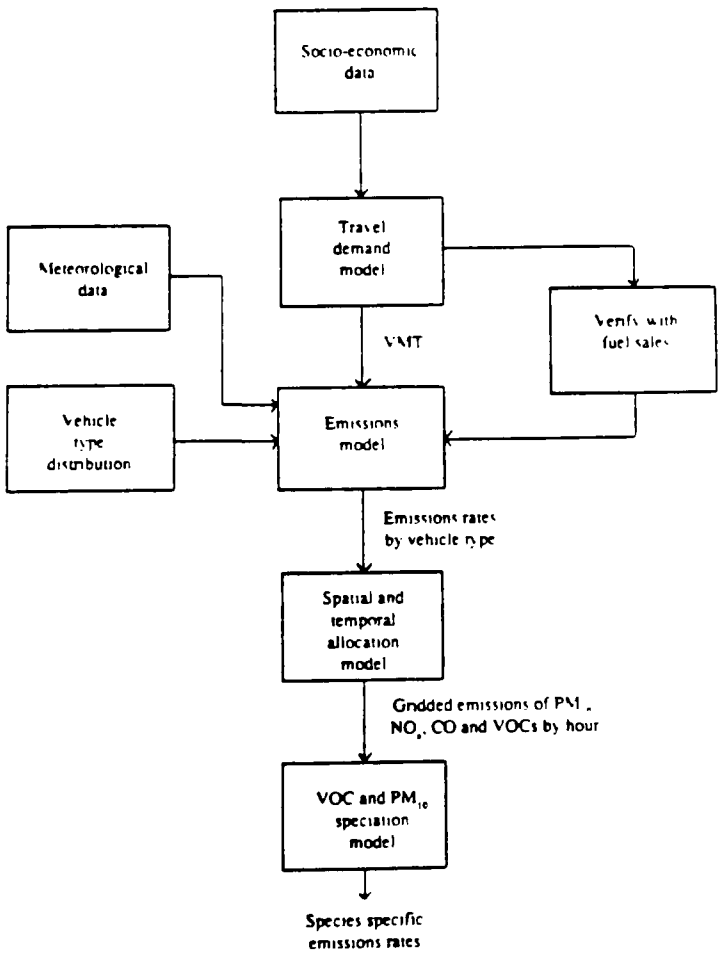

Figure 5. DRI Emissions Modeling System (Appendix B, page B-13)

According to DRI, today's standard definition of an air quality emissions inventory as a spatially and temporally averaged listing of presumed emissions is outdated. Consequently, they believe that an EMS consisting of special-purpose modules which can be updated with new information and new science when they are available and activity levels and emissions/activity relationships specific to the area being modeled will be more helpful. An EMS would also contain error propagation algorithms to provide precision estimates on outputs and use independent activity data bases and emissions/activity relationships of equivalent quality to estimate accuracy. Similarly, it would adjust the emissions/activity relationship in response to environmental variables, especially meteorology, and allow the addition, subtraction, or modification of emissions for specific days. Finally, it would retain the ability to trace the information to allow quality auditing and provide output displays, statistics, and data bases which could be used for modeling, data analysis, and quality assurance. For an EMS which contains all these attributes, DRI suggests referring to the one being developed by the San Joaquin Valley Air Quality Study and Atmospheric Utility Signatures, Predictions and Experiments (SJVAQS/AUSPEX) in California.

DRI offers a two-step method for validating the emissions factor model. The first involves an operational evaluation of the model including a vehicle fleet test which the experimenter specifies and controls. The user would apply the model to calculate absolute emissions factors, and stated uncertainties therein, and compare them with observations of known accuracy, precision, and validity. DRI believes that this first step will permit reformulation of the model inputs, given the knowledge of the distribution of modes, speeds, grades, and other operating conditions, to accurately predict observed on-road results. Step 2 involves testing the adjusted model in a real-world setting where a user can validate it against actual driving conditions. Here, remote sensing would be used to tell where model inputs may be off and to yield information necessary for determining actual instantaneous vehicle emissions rates.

Among the conceptual designs which basically follow the current methodology, Radian Corporation's conceptual design provides perhaps the most detailed approach to vehicle emission modeling. Radian believes that its motor vehicle source (MV) model (Figure 6) will accurately generate hour-by-hour link specific emission estimates for urban areas, based upon the development of travel demand estimates obtained from a transportation modeling system (TMS) designed specifically for air quality-related analysis (i.e., on-network travel demand estimates). According to the contractor, the MV model will also accommodate transportation estimates developed for rural areas through off-network transportation models. Radian bases its MV model upon the development of emission factors, on a grams/hr basis, for a pre-determined number of

driving cycles or a driving cycle/emission factor matrix for different combinations of roadway types (including minor collectors and residential streets) and area types (e.g., central business district, rural, entrance/exit ramps, etc.). This matrix (Figure 7) will be stratified by peak and off-peak travel periods. Each link in a given transportation network will be classified according to its use and matched to a particular driving cycle and corresponding emission factor. Emission factors will be developed for each driving cycle on a per-hour basis, based upon the use of a separate modal analysis model. Once the composite facility type/area type driving cycle emission factors are calculated, the emission factors are combined with the vehicle activity data developed from the transportation models for each link and node. The activity data will include: (1) the total vehicle hours (VHT) traveled on a link; (2) the distribution of VHT by vehicle type and fuel type for each link; (3) the number of cold and hot starts for each node; and (4) the number of park hours for each node (diurnal and hot soak emissions). Radian concludes that the product of the emission factors and the vehicle activity data will be exhaust and evaporative emission estimates by individual link and node for each hour of the day.

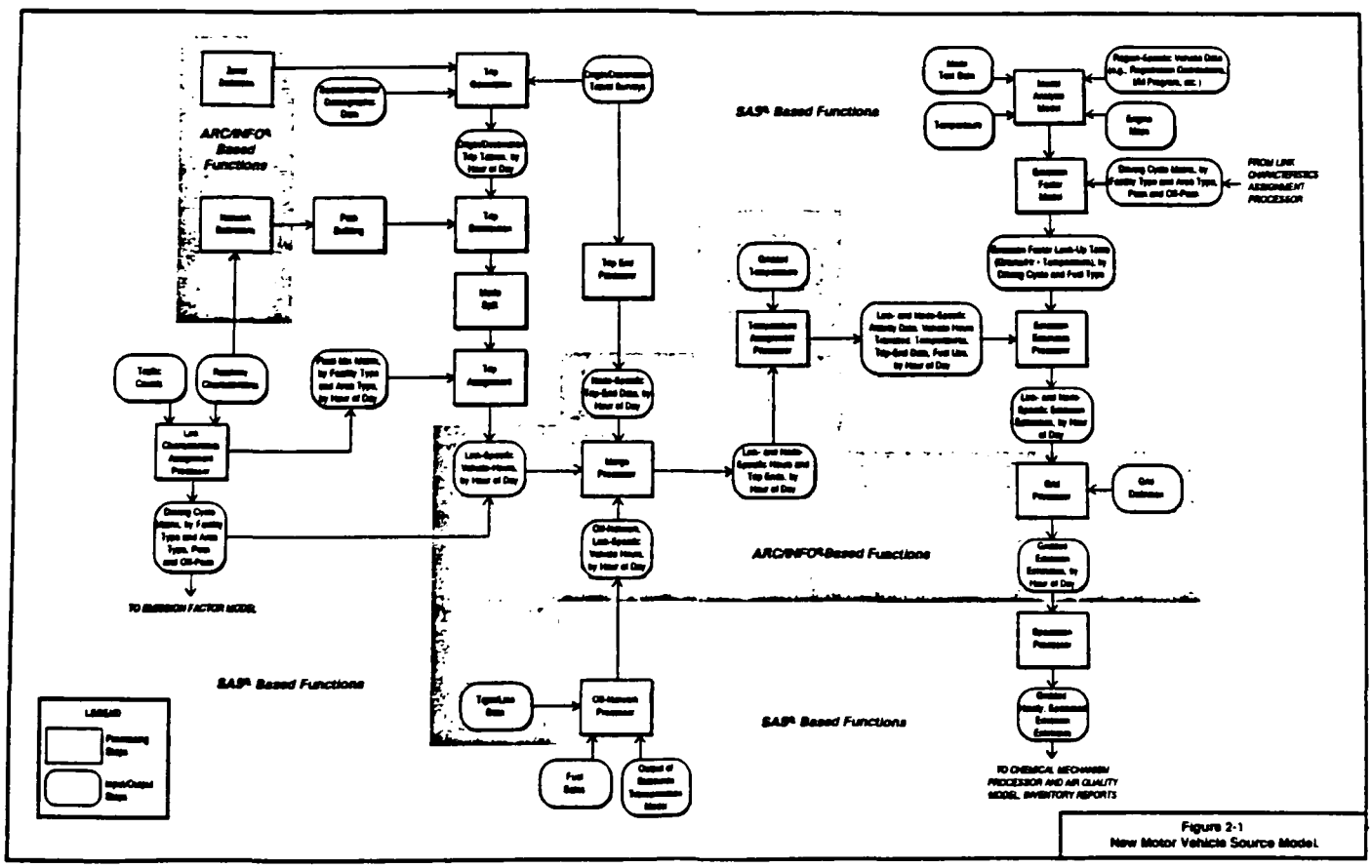

Figure 6. Radian Motor Vehicle Source Model (Appendix D, page D– 2-2)

	Facility Type							
Area Type	Freeway	Expressway	Major Arterial	Minor Arterial	Major Collector	Minor Collector	Residential Streets	Entrance/ Exit Ramps
Central Business District (CBD)	11*	12	13	14	15	16	17	18
Urban	21	22	23	24	25	26	27	28
Residential	31	32	33	34	35	36	37	38
Commercial	41	42	43	44	45	46	47	48
Suburban	51	52	53	54	55	56	57	58
Rural	61	62	63	64	65	66	67	68

* *ij* matrix cell address for: Driving cycle (peak)*ij*
Driving cycle (off-peak)*ij*

Figure 7. Driving Cycle Matrix (Appendix D, page D– 3-5)

Radian suggests using tunnel studies, remote sensing and source apportionment techniques to verify the emission estimates generated by the MV model; and data from fuel sales, traffic count programs, and satellite imagery to verify its transportation estimates.

Alliance Technologies Corporation's (hereafter Alliance) conceptual design consists of two basic levels. First, a large modeling system, or "Metamodel" (Figure 8), which consists of a broad range of integrated computerized methods, procedures, and data sources as well as other types of components, information, and activities related to vehicle emission estimation. The Metamodel's purpose is to provide an overall structure within which vehicle inventory methods can be developed and tested and which data can be processed and stored. Alliance believes that this will allow for the updating of new methods and data as they develop. The Metamodel consists of a set of modules that would include computerized methods and data or ongoing research and analysis

that would be the basis for potential methods. Alliance concludes that the development and testing of multiple data sources and alternative methodologies within the Metamodel will permit internal validation within Metamodel modules and in the combined application of the modules. The Metamodel would also require a flexible set of methods allowing interaction between modules, and a set of statistical tools for analysis of Metamodel methods and data.

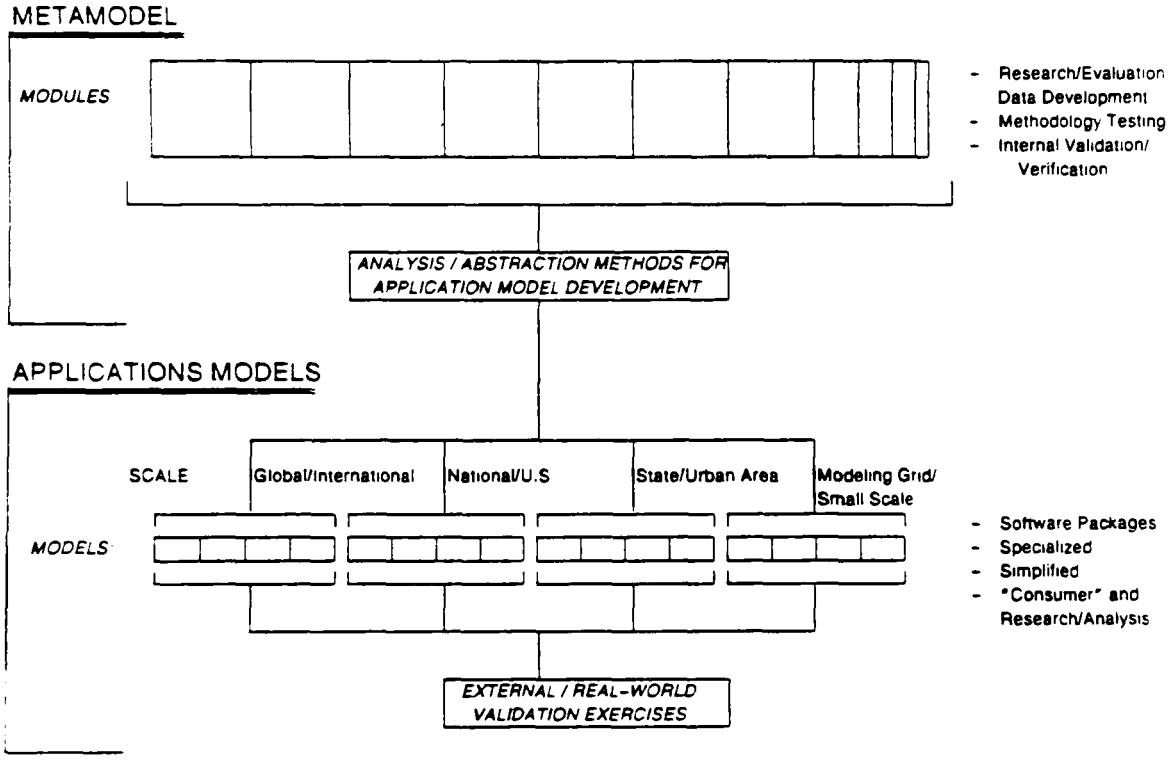

Figure 8. Metamodel (Appendix A, page A-18)

The "Applications Models" comprise the second level of Alliance's conceptual design. These models would include individual software packages developed for specific vehicle inventory cases. Alliance states that these will be more specialized than EPA's MOBILE4 and relatively simple in structure and data and therefore easier to understand and apply. The Applications Models contain data and methods relevant to a specific type of use, with simplifications or default values

where the use allows. These would be designed for a specific type of application, but will also be adaptable by reprogramming them using the Metamodel as source material.

Alliance suggests that in order to have parallel structure between the Metamodel and the Applications Models, the Applications Models should contain all or most of the same modules as the Metamodel, simplified to suit the specific application. The modules can be arranged along a continuum from emissions testing to transportation data, with control strategies and information sources functioning more as auxiliary components that apply across the rest of the Metamodel. Alliance says that the modules are not strictly defined as computerized components in a modeling system, but are more like "activity areas" or ways of dividing the overall field of vehicle emission estimation into a manageable number of logical pieces which can also correspond to parts of a modeling system.

Of the six contractors' conceptual designs, Systems Applications International's (SAI) conceptual design deviates most significantly from the current methodology being used. SAI suggests a three step interrelated process for more accurately determining vehicle emissions inventories. First, determine the base case emissions (Figure 9) for an area using an activity factor model (based not on VMT, but on vehicle operating mode distributions by area and time) and a modal emissions factor model. Second, for forecasting purposes, synthesize the distributions of the base case emissions inventory by using transportation planning models and small scale models. Third, each step in the above process should be subjected to independent verification of its performance under actual conditions.

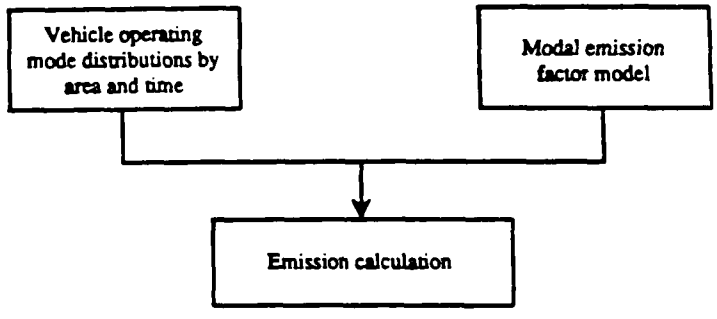

Figure 9. Base Case Emission Estimate (Appendix F, page F–12)

SAI believes that reliance on overly aggregated representations of both vehicle operations and emissions is the primary cause of the limitations in the current model. SAI's main approach for fixing these problems is by using substantially increased reliance on empirical inputs in their proposal. The basic emission calculation is the numerical integration of emission rates, within designated areas, of a vehicle operating mode distribution and a modal emission factor. The emission rate for vehicles within area i for hour h is given by: $\int_v e(v)dF_{ih}(v)$, where

v = a vector describing the state and operating mode of a vehicle (it can consist of basic operating modes, speed, acceleration rate, canister state, fleet characteristics, environmental conditions, trip end, etc.)

$F_{ih}(v)$ = the distribution function of vehicle operating modes within an area i for hour h evaluated at vehicle state vector v (to be determined by aerial photography and computer image processing)

$e(v)$ = the emission rate (mass/time) for a vehicle in state v.

Total emissions are given by: $\sum_{i,h}\int_v e(v)dF_{ih}(v)$.

SAI contends that since the empirical distributions $F(v)$ are static, they cannot be directly used to develop future year forecasts. In the course of developing empirical distributions through multiple hours and days of aerial photograph analysis, however, data will be collected that show the sensitivity of these distributions to variations in total network loading. SAI believes that these data showing sensitivity to change provide the basis for forecasting. SAI defines a new distribution $F'(v)$ to allow the use of transportation planning model outputs for forecasting. This new distribution is a synthesized distribution based on a parameterization using transportation model outputs (Figure 10). SAI uses the following additional notation:

w = a vector of parameters that are outputs of the transportation planning model and that correspond to measures of overall network loading in the data base used to develop $F(v)$

$G_{ih}(v|w)$ = the observed distribution of vehicle operating modes v in area i for hour h, given that the network state is w

$G'_{ih}(v|w)$ = a mathematically constructed distribution whose parameters are given by w that has been shown to be essentially identical to $G_{ih}(v|w)$.

Then $F'_{ih}(v) = G'_{ih}(v|w_o)$, where w_o is the "average network state" for the base case. SAI believes that the development of mathematical forms for G', the "calibration" of F', and the verification of agreement between F' and F will be a key aspect of developing forecasting capability based upon this proposed approach. With future conditions denoted with an asterisk *, the contractor contends that future year base case emissions will be given by: $\int_v e^*(v)dF'_{ih}{}^*(v)$,

where $F'_{ih}{}^*(v) = G'_{ih}(v|w_o^*)$.

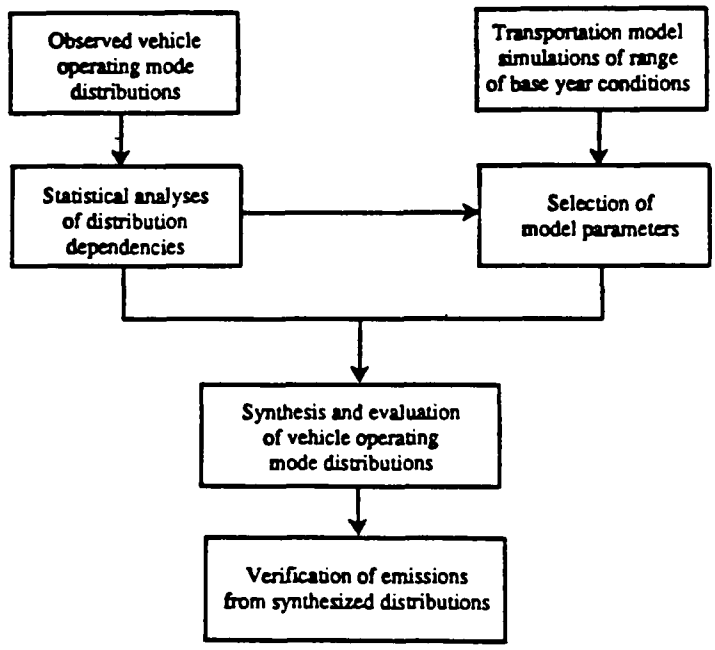

Figure 10. Development of relationships for synthesizing and forecasting vehicle operating mode distributions (Appendix F, page F–14)

SAI's estimation of control effects closely parallels existing practices (Figure 11). SAI contends that there are three types of controls: (1) those that affect vehicle emission rates (e.g., retrofit technologies, reformulated fuels, etc.); (2) those that affect trip generation (e.g., ride

sharing measures, growth management, etc.); and (3) those that affect vehicle operations (e.g., flow improvements, elimination of drive-up windows, etc.). Depending on the specific measure, the simulation of controls could involve either the modal emissions factors (e.g., reformulated gas), the future year transportation model forecast parameters (e.g., employee based trip reduction), or the relationship between transportation forecasts and the synthesized distribution of vehicle operating modes.

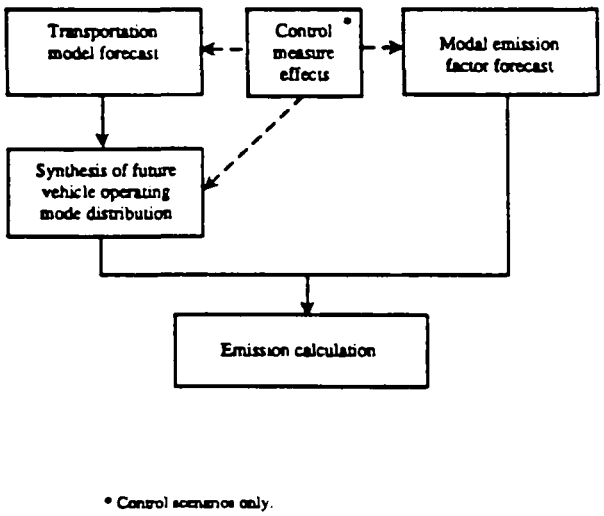

Figure 11. Development of future year emission forecasts (Appendix F, page F–16)

SAI believes that each step in the estimation process should be subjected to independent verification of its performance under actual conditions. SAI suggests several measures for verifying the aerial photography and image processing incorporated in the vehicle operating mode distributions. First, by equipping marked vehicles with accelerometers, fuel consumption and emission measurement instruments, and position recording equipment, and verifying the accuracy with which aerial photographic techniques estimate mode, speed, acceleration, and emissions. SAI says that this technique can also be used on a "trip" (as opposed to area) basis to identify spatial differences in operating mode distributions, and as a check on the area wide distributions of operating modes. Second, by conducting "audits" using video techniques, loop counters, and other fixed-location data, to determine how accurately the primary method describes roadway dynamics. Third, by use of video-based license identification techniques to verify the age distribution of in-use vehicles, and the variability of this distribution by time and location. SAI

suggests that remote sensing techniques in conjunction with registration-based identification of vehicle age and technology can be used to verify the accuracy of the modal emissions factors.

REFERENCES

Wilson, J. H., Jr. Proceedings of Two Highway Vehicle Emission Inventory Workshops. EPA-600/9-91-007 (NTIS PB91-168492), U.S. Environmental Protection Agency, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, March 1991.

APPENDIX A

Technical Memorandum:

Conceptual Design for a New Highway Vehicle Emission Estimate Methodology

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EPA Contract No. 68-D9-0173
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JULY 1991

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INTRODUCTION

In response to the EPA request for a "Conceptual Design for a New Highway Vehicle Emission Estimate Methodology," this paper outlines an overall approach and structure that can be used in long-term planning for highway vehicle emission inventory methodology improvement. The first section describes the basic concepts of the proposed approach. The next section describes the modules that would initially comprise the model set, including interactions between them, potential inputs to and outputs from each module. Following sections address potential additional modules, integration of modules and development of specific Applications Models, validation methods, and implementation of this conceptual design.

BASIC CONCEPTS

The conceptual design proposed here consists of two basic levels. One level is the Metamodel, and the other consists of a number of Applications Models. These levels are depicted in Figure 1, and are outlined briefly below. (Figure 1 is a schematic; more details are provided in later figures and text.) Table 1 provides a comparison of the essential characteristics proposed for the Metamodel and the Applications Models. Further details are provided in following sections.

The Metamodel

The Metamodel is a large modeling system which consists of a broad range of integrated computerized methods, procedures and data sources as well as other types of components, information and activities related to highway vehicle emission estimation. The prefix "meta-" was chosen because one of its definitions is "more comprehensive: transcending."

The purpose of the Metamodel is to provide an overall structure within which highway vehicle inventory methods can be developed, tested and evaluated, and in which data sources related to highway vehicle inventory development can be assessed, processed and stored. It could be considered a clearinghouse or repository for data and research related to highway vehicle inventories as well as a framework or tool for research, analysis and creation of inventories and inventory methods.

The Metamodel structure provides the opportunity to maintain and update methods and data for highway vehicle inventories as new developments in mobile source emissions and the state of the art of understanding of how these and other aspects affect highway vehicle emissions. The Metamodel would be structured and planned to allow incorporation of additional data sources as new data become available over time, or existing data become relevant, due to changes in mobile source inventory needs, transportation systems, vehicles, fuels or other factors.

The Metamodel would consist of a set of modules that could each include components ranging from highly articulated computerized methods and data to ongoing practical and theoretical research/analysis that would provide the basis for potential methods. At full development, it would include the results of all relevant research as well as documentation of the derivation/basis for the computerized portions of the Metamodel.

Within the Metamodel, multiple data sources and alternative methodologies for highway vehicle inventories can be developed, tested, compared and documented. To the extent that information and methods allow, this would permit internal validation/verification as well as sensitivity analyses of

potential options both within individual Metamodel modules and in the combined application of these modules.

In addition to the individual modules, the Metamodel would also require:

(1) a highly flexible set of methods and procedures allowing interaction and coordination between the modules, and

(2) a set of statistical and modeling tools for analysis and abstraction of Metamodel data and methods, which would also be used in the development of the Applications Models.

Applications Models

Applications Models would be individual software packages developed for specific highway vehicle inventory cases. They would be somewhat more specialized than the current MOBILE emission factor model series, which has been adapted to allow use in a variety of different contexts. By being restricted to more limited uses, the Applications Models can be relatively simple in structure and data requirements, and can be easier to understand and apply. These Applications Models would include both "consumer" versions for regulatory highway vehicle inventory requirements (such as State Implementation Plans) as well as "research and analysis" versions that could be used to provide mobile source inputs to environmental assessment programs and regulatory development efforts at the national or international scale. In addition, special-purpose Applications Models could be developed for model verification/validation exercises, by extracting from the Metamodel the best available information and methods for the specific situations being used in a given exercise.

The Applications Model concept is somewhat analogous to the number of models currently available for simulation of ambient air quality for different purposes, at different scales and under different conditions or levels of data requirements.

TABLE 1. CHARACTERISTICS OF THE METAMODEL AND APPLICATIONS MODELS

METAMODEL	APPLICATIONS MODELS
Comprehensive – Incorporating all available state-of-the art knowledge related to highway vehicle inventory methods and data.	**Application-oriented** – Contains data and methods relevant to a specific type of use, with simplifications or default values where the use allows.
Flexible – Capable of accepting new modules, methods and/or data at any time.	**Relatively "hard-wired"** – Designed for a specific type of application, but adaptable by reprogramming using Metamodel as source material.
Redundant system design – Multiple methods and data sources wherever possible, for comparison and validation.	**Minimal options for methods and data** – Using only what is necessary to provide the outputs for the desired application; few alternative methods, alternate data sets or inputs only as required.
Mainframe or large minicomputer-based – Combination of standard programming language (e.g., FORTRAN, to interface with MOBILE models) and analytical/data-handling capability (e.g., SAS).	**Personal computer-based** – User-friendly model structures based on FORTRAN, or dBase or spreadsheet formats where feasible.

THE MODULES

The intent of the Metamodel/Applications Model concept is to have a parallel structure between the Metamodel and each of the Applications Models. Figure 2 presents an expansion of the Metamodel section of Figure 1, showing basic modules envisioned as a starting point for all models. While this Figure is specific to the Metamodel, most Applications Models would involve some data and methods from each of the Metamodel modules, and thus would have all or most of the same basic modules, simplified to suit the specific application. As indicated in Figure 2, the model structure and software would be designed to accommodate additional modules which might be created in the future. While Figure 2 does not attempt to specify relationships between the modules (see individual module descriptions for this), it does arrange the modules along a continuum from emissions testing to transportation data, with control strategies and information sources functioning more as auxiliary or overlay-type components that apply across the rest of the Metamodel.

The following pages provide a general description of the purposes, outputs, data requirements and sources, and interactions with other modules that might characterize each module. These descriptions are not intended to be complete or definitive, but rather to suggest possibilities in the area each Module might cover. They are based on current understanding of factors and data sources relevant to highway vehicle emission estimation, and thus would be expected to change with more detailed examination of system requirements and interactions as well as with the availability of new data sources in the future. Where possible, potential future data sources have been noted as well as those currently available.

As indicated earlier, these modules are not strictly defined as computerized components in a modeling system, but might best be thought of as "activity areas," or ways of dividing the overall field of highway vehicle emissions estimation into a manageable number of logical pieces, which can also correspond to (or contribute to) parts of a modeling system.

Attachment A lists citations and brief abstacts of many of the data sources mentioned in the individual module descriptions below.

MODULE: **Emissions Test Data / Emissions Relationships**

PURPOSES: To be a primary repository/index of available data from emissions testing programs (U.S. and worldwide)

Provide a set of alternative structures by which emissions data can be used to develop relationships between emissions and predictive variables (activities and conditions)

Supply state-of-the-art predictive relationships (emission rates or equations) to the Applications Models

OUTPUTS: Emission rates, equations or other relationships for the entire universe of vehicle-related emissions (including, but not limited to: speciated hydrocarbons, NO_x, CO, PM-10, CO_2, CFCs, toxics, asbestos and engine fluids)

Assessments of adequacy of existing emissions testing procedures and databases

DATA REQMTS/SOURCES: Emissions test data from all potential sources, including OMS and CARB regulatory and research programs, Certification testing for vehicle and engine families, private/industry sources, State I/M programs

Additional data on the conditions, techniques and assumptions used in each set of tests

INTERACTIONS: Extensive interaction with Vehicle Fleet module to direct testing and analysis toward adequate coverage of current and future fleets

Extensive interaction with Driving Behavior module to improve identification of relevant variables for emissions estimation, and to isolate and quantify the effects of these variables in emission testing as well as in development of emission rate prediction tools

Interaction with the other modules to collect and assess potential activity and condition data sources, and to develop sensitivity to emissions control strategies in the emission relationships

COMMENT: Although vehicle emissions testing itself is not considered part of this module, one function of this module would be to combine available test results with explanatory data and assess the ways in which current testing procedures and databases do not meet the needs of the predictive process. Thus part of the analytical work done in this module would be to identify weaknesses in the current testing procedures and datasets. This would result in suggestions regarding improvements that can be made to testing programs and methods.

MODULE: **Vehicle Fleet Characteristics / Technology / Fuels**

PURPOSE: To provide a sufficiently-detailed description of the highway vehicle fleet to support analysis, development and implementation of state-of-the-art emissions relationships. This would include current and historic databases as well as the ability to create and apply alternate future fleet scenarios.

OUTPUTS: Fleet profiles for analysis years from 1920 to 2050, broken down by vehicle type, fuel, technology and county

Data on vehicle histories and use (mileage accumulation, tampering with control devices, misfueling and other factors that may influence emissions characteristics)

DATA REQMTS/SOURCES: R.L. Polk and Co. registration information

Mileages, tampering and other data from state I/M programs

Additional data from MVMA and follow-up activities by vehicle manufacturers

Vehicle history and use data should begin to be available from on-board vehicle monitoring systems (data dumps from future "black boxes") -- could be collected as part of I/M program data acquisition or through manufacturers' recall/follow-up efforts

INTERACTIONS: Primary interactions with the Emissions module (defining the universe that emissions relationships need to describe, supplying the data to characterize the emitting fleet in a specific year and location)

Supplying fleet data to the Driving Behavior module and the Transportation Activity module to support analyses of what behaviors and activities are relevant to emissions prediction

Interaction with Emissions Control Strategies in development of vehicle-type-specific control strategies and control strategies that consist of introduction/encouragement of specific technologies or vehicle types

MODULE: **Driving Behavior / Modes and Transients**

PURPOSES: To facilitate the development of improved understanding of (1) what aspects of driving behavior can affect emissions rates, (2) how the behavior of individual drivers can influence emissions, and (3) how driving behavior can be characterized to produce maximum sensitivity to emissions-determining aspects

To develop and maintain a primary database of driving behavior that can be used in emissions testing/research and in development of methods to predict emissions

OUTPUTS: Analyses and data on driving behavior that can be used to guide emissions testing and research concerned with sensitivity to driving behavior and the reaction of various technologies to driving behavior

Databases and characterizations of driving behavior (e.g. statistically-derived functions or profiles) for use in Applications Models

DATA REQMTS/SOURCES: Existing and on-going studies of how drivers use the transportation network (e.g. chase car studies and other on-road behavior characterization work) and how different vehicles react to specific aspects of driving behavior (testing heavy accelerations, low and high speeds and other possible transient high-emission patterns)

Future programming and retrieval of "black box" on-board recordings of actual driving patterns on a large scale

Coordinated studies of areas believed to be characterized by specific driving behaviors or modes of interest, such as joint monitoring of on-road speed/acceleration and localized ambient measurements

INTERACTIONS: Primary interaction with Emissions module, supplying behavior data and receiving emissions test data to analyze for behavior-sensitive aspects

Additional interaction with the Transportation Systems and Activity modules, to coordinate the development and analysis of transportation data that can be used to predict important aspects of driving behavior, and with the Vehicle Fleet module, in assessment of the interaction between technologies and driving behavior.

COMMENT: This module would concentrate on alternative methods and data that can be used to describe driving behavior, including the current "typical behavior" Federal Test Procedure approach, and other methods that allow discrete assessment of individual driving modes and transient events that are becoming more important with the improvement of our understanding of emissions, driving styles and vehicle technology (especially engine control systems and programming).

MODULE: **Transportation Systems -- Networks, Data, Planning**

PURPOSES: To develop transportation system information to support the other modules

To develop improved methods to simulate and assess system/facility-based transportation control measures

To promote the integration of transportation planning and emissions estimation and control (e.g. development of an Applications Model that can be attached to urban transportation models for use in system planning)

To provide support for gridding/spatial allocation of emissions estimates

OUTPUTS: Characterization of highway systems with respect to emissions-related parameters (speeds, slopes, lane widths and configurations, intersections/signals or other items that may be identified as significant in future research, as well as systems-related transportation control measures)

DATA REQMTS/SOURCES: Transportation system networks and related data developed for local/corridor areas (project studies), urban/regional simulations (UTPS-style network models) and national applications (Federal-Aid network data and Highway Performance Monitoring System county-level roadway files)

Advanced data acquisition concepts such as (1) use of the U.S. Geological Survey "GeoData" digitized cartographic information system to develop special-purpose datasets on area-specific road system extent and characteristics (e.g. slopes derived from topography -- see attached summary of the GeoData project) and (2) use of remote sensing combined with Global Positioning System for integrated collection of highly detailed data on roadway and local conditions (traffic flow/activity). The latter is a concept in development by FHWA, which could be expanded to include collection of data on other areas of concern such as driving behavior, vehicle function and on-board emissions monitoring.

INTERACTIONS: Primary interactions would be with the Transportation Activity module, providing the basic system description information for activity modeling, and with the Driving Behavior module, providing data on specific transportation system characteristics that affect driving behavior, as well as interacting with both of these modules to identify data needs and improve the available database.

MODULE: **Transportation Activity Data and Modeling**

PURPOSES: To provide an analytical structure for the development and assessment of alternative activity measures for emission estimation

To develop and maintain an up-to-date set of basic reference statistics and tools for analysis of activity measures and for support activity data needs of Applications Models

OUTPUTS: Activity measures for use with Emissions module relationships in Metamodel exercises and in Applications models

Assessments of the utility, accuracy and other aspects of individual and combined activity measures for highway vehicle emission estimation, and alternate methods for activity measure development and application

DATA REQMTS/SOURCES: "Standard" sources of transportation activity data (VMT, trip ends and traffic/congestion data), including urban transportation modeling and traffic counts in individual urban areas, Highway Performance Monitoring System (HPMS) data as reported in *Highway Statistics* and HPMS data files, and periodic State/local transportation agency studies and statistical summaries

A number of potential sources of data which currently appear to be of marginal utility but which could be utilized with adequate analysis and/or some changes or additions to the focus of the data-gathering efforts. These include the Bureau of Census *Urban Transportation Planning Package* (a sample of the Decennial Census), the Department of Energy *Residential Transportation Energy Consumption Survey*, and the Federal Highway Administration *National Personal Transportation Study* series (See second COMMENT, below.) These sources are concerned mainly with trip-making behavior, fuel use/refueling behavior, travel time/distance and associated demographic and economic variables.

Highway fuel use data, available at the state level and occasionally at the county level from state tax authorities

Population, income, and employment data from the decennial *Census of Population*, at levels as fine as Census blocks

Vehicle population data, available from individual state Departments of Motor Vehicles but more readily in a national database from R.L. Polk and Company.

Vehicle usage data – potential sources include development of mileage accumulation databases from odometer readings collected by I/M programs and "black box" on-board data storage systems

INTERACTIONS: Primary interaction would be with the Emissions module, in the use of activity measures with emissions relationships to estimate emissions, and with the Transportation Systems module, to integrate the available activity data into the physical landscape of the city or nation for analytical or allocation purposes

The Transportation Activity module data and methods would also have to be coordinated with each of the other modules, since activity measures would have to be related to descriptions of driving behavior, the specific vehicle types involved and emissions control strategies designed to affect activity levels.

COMMENTS: Since activity levels are, along with emissions rates or relationships, the key parameters used in calculating emissions, it is especially important not to restrict the types of activity levels that could be applied in future emission estimation methods, or the research that will lead to these methods and data sources. In particular, there are numerous logical possibilities for the development of Applications Models that depend on different activity variables, or that use multiple variables to predict different types of emissions. One current case in point is the use of miles travelled to estimate exhaust and running loss emissions and trip-related data to estimate start and diurnal evaporative emissions. In particular, estimation of "unconventional" emissions such as CFCs from air conditioning systems or fluid losses from other engine components might be much less dependent on vehicle use than other factors such as weather or maintenance practices. Especially important will be the development of activity indices that can be coordinated with future data on highly specific transient or modal emissions phenomena.

In all the cases of existing surveys mentioned above, the agencies collecting the data are amenable to addition of items to the survey instruments and expansion of the samples or areas of coverage (for a price). Significant lead time is necessary for such efforts, and surveys are notoriously expensive and subject to major concerns of sampling and validity at different geographic scales. However, the time horizon and possible scale of this research effort indicates that each of these possibilities should be explored in depth.

MODULE: **Emissions Control Strategies**

PURPOSES: To allow simulation of the potential effects of highway vehicle-related control strategies on emissions from the local to national and global scales

Control strategies of concern would include the "traditional" I/M and anti-tampering programs and activity- and facility-related transportation control measures, but would also include fuel-based strategies (oxygenated, reformulated and alternative fuels), vehicle- and technology-based strategies and economic or market-based incentive or penalty programs

OUTPUTS: Descriptions of potential control strategies and their effects on activity or emission levels, including "mini-models" of the effects of specific program parameters on overall effectiveness or penetration of the program

DATA REQMTS/SOURCES: Technical studies of individual and combined emission control programs and strategies, as well as application of these data within the proposed Metamodel framework to generalize from the results of specific studies

INTERACTIONS: This module would be used to develop descriptions of the predicted effects of emissions reduction/control strategies that can be applied in any of the preceding modules, depending on the type of strategy. Potential control strategies may cover the entire range of modules, but individual control measures will typically fall mainly in the area covered by one or two modules. For example, I/M programs would be described by changes in Vehicle Fleet Characteristics, whereas integrated transportation control measure programs would involve Transportation Systems and Activity and possibly Driving Behavior.

MODULE: **External Conditions / Information Sources**

PURPOSES: Provide input data required by other modules and by "consumer-level" Applications Models

Interface with original sources of data

Acquire and process data on "standing order"

Maintain current and historic data files

Provide analyses of specific data sources to reduce data requirements

OUTPUTS: Data for other modules and models (see below)

DATA REQUIREMENTS/SOURCES: As identified in the development of other modules and models

COMMENTS:

This module would serve as a pre-processor and data acquisition utility for periodic or irregular data sources that have been defined in other modules and models. It would include a tracking and ordering system which would track and verify when revised versions of current module datasets become available and then obtain the updated data and process it for input to the relevant modules. It is anticipated that the types and amounts of data that can be accessed and processed in this way would increase as the level of activity in motor vehicle emission estimation increases and as existing data sources are transformed into more useful tools in this area. One particular function of this module would be to assemble and make available data from numerous sources required for ozone/CO nonattainment area mobile source inventories that would otherwise have to be collected individually by each state or local agency.

Examples of current data sources that would be handled in this way include:

- Annual data sets from the Highway Performance Monitoring System, *Highway Statistics*, MVMA annual *U.S and World Motor Vehicle Data*, and other sources.

- Other periodic or irregular data sets such as surveys of travel behavior by U.S. Bureau of Census (the Transportation Planning Package), FHWA and DOE.

- Additional data resource/processing opportunities include collection of ambient monitoring data from the EPA National Air Data Branch and climatic data from the National Weather Service Climatic Data Center, and joint processing of these data to provide statistical abstracts which describe the temperature and other conditions on days with high ambient pollutant levels. This could be a generalization of the current requirement for development of temperature data for high-level ozone days for MOBILE model applications.

POTENTIAL ADDITIONAL MODULES

The conceptual and data-processing structure of the Metamodel would allow addition of modules as the need arises. For example, entirely new vehicle or fuel technologies may require other capabilities or raise new concerns as to environmental impacts that have not been addressed in the modules discussed above. New data-development possibilities will exist in the future that cannot be predicted today. Two specific additional modules are discussed briefly below.

One additional module that could be implemented in the near term is a separate "Fuel Use/Fuel Economy" module. While the Transportation Activity and Vehicle Fleet Characteristics modules would include these types of data and analyses, the mission of the overall modeling structure could easily be expanded to include modeling and projection of fuel use and fuel economy. This will become more important as the number of alternative fuels and the levels of their usage increase in the next ten years. This module could be used to do independent analyses of fuel-related issues, using the supporting data and methods already available in the rest of the modeling structure. The draft Alliance report "Methods and Data for Developing Vehicle Miles Traveled and Speed for Highway Mobile Source Emission Inventories" describes and reviews a collection of references which include methods and data relevant to this area, which are listed in Attachment A.

Another potential additional module which would relate to a Fuel Use/Fuel Economy module would be a Fuel Production and Distribution module. In the current context of an oil-dominated transportation system, this module would integrate desired aspects of the oil production, refining and distribution into the modeling structure, and have the capability to simulate the effects of transportation, vehicle and fuel-related policies and technologies. This module could provide a tool for looking at the "full picture" of secondary and tertiary emissions that are related to the present transportation system, including (1) fuel storage, transportation and distribution; (2) exploration, extraction and refining; (3) construction and maintenance of the transportation network itself. This module could take advantage of the numerous models and extensive databases that already exist in each of these areas, focusing on the ways in which those models can be used to address emissions-producing activities. In addition, this module could take advantage of available and ongoing EPA and DOE research on the entire fuel-related economic sector, including investigations of air emissions and other environmental effects.

In addition, a Fuel Production and Distribution module would provide the structure and transportation/energy demand data to model similar aspects of alternative fuels. In the case of alternative liquid/gas fuels, some of the oil-based system could be used, with additions to account for different methods of production or delivery. In the case of electric vehicles, fuel cells, photovoltaic hydrogen, various hybrid vehicles and other developmental technologies not as tied to the oil-based economy, the ability to simulate effects on utility demands and other energy sources becomes more important. Developing a module that can address this level of analysis is obviously a major undertaking, potentially the size of the rest of this model structure. On the other hand, the fact that future changes in the transportation fleet/system in individual areas or across the nation may direct the major environmental impacts of the system away from on-road emissions and towards fuel/energy production and distribution systems is highly relevant to the overall modeling concept being discussed here.

METAMODEL INTEGRATION

Integration of the modules and individual components of the Metamodel can be thought of on at least two levels:

- Direction and facilitation of the research and analysis efforts that comprise the "front end" of the Metamodel, developing and applying an overall perspective as to the missions and functions of the entire modeling system (Metamodel and Applications Models), of related research and regulatory efforts, and of appropriate interfaces between external activities and modeling system development.

- A highly-flexible set of analytical methods and data-processing procedures allowing interaction and coordination between the computerized portions of the modules. Although there may be some individual areas in which specialized software or database management tools could be applied (e.g. existing modeling systems, relational databases), it would be highly appropriate to establish a common language (e.g. FORTRAN) and documentation procedures as standards across the entire Metamodel/Applications Models system. This would be especially critical if different components are to be created by groups in a number of different locations and organizations.

  In addition to providing for the basic functioning of the Metamodel at the data-processing level, this integrative structure would include a capability for conducting sensitivity and uncertainty analyses across all Metamodel modules, which can be used on an ongoing basis to identify areas most in need of support and assessment.

ANALYSIS/ABSTRACTION METHODS FOR APPLICATIONS MODEL DEVELOPMENT

Creation of Applications Models from Metamodel components will require a similarly flexible (yet uniform) set of statistical and modeling tools for analysis and abstraction of Metamodel data and methods. For simplicity of analysis, use of one basic package of analytical/statistical software such as SAS should be encouraged wherever possible. In some cases, the appropriate tools might be special-purpose versions of software already developed within the Metamodel. In either context, the Applications Model concept would be implemented by:

- developing criteria for the proposed application

- identifying Metamodel modules and sub-components that are relevant

- assessing the levels of sensitivity of the proposed application to the relevant Metamodel methods and data

- identifying ways in which full-blown Metamodel components can be abstracted or simplified for the particular application

- developing and testing an Applications Model based on the above information

POTENTIAL APPLICATIONS MODELS

Figure 3 shows the lower portion of Figure 1, expanded to show a number of candidate Applications Models that this concept could support. The specific models shown here represent the current range of applications of highway vehicle emission estimation techniques, with a few other developmental or anticipated applications. These include two general types of models:

- "Consumer-level" models such as those designed for development of ozone and CO State Implementation Plan inventories, for the integration of emissions estimates into urban transportation planning, or for most other smaller-scale applications. The major exception is specialized Applications Models created for use in local-scale studies for emissions methodology validation.

- Larger-scale models which are generally oriented toward research or policy/regulatory analysis goals.

Determination of the need for specific Applications Models would be a function of the eventual organization and support available for activity in this area. Initial development of any given type of Applications Model would be followed up by tracking of Metamodel method and data changes that affect existing "active" Applications Models, and periodic updating of relevant parts of those models or "regeneration" of the models or data sets as appropriate.

VALIDATION METHODS

The proposed Metamodel/Applications Models structure would allow a variety of opportunities for validation/verification efforts regarding highway vehicle emissions estimates and the supporting models and data sources. Figures 4a, b and c are schematic depictions of three general types of validation exercises that are possible, as follows:

- Within Module -- Figure 4a shows a situation in which multiple methods or data sources can be used for assessments or calibrations of methodologies within a single module. This example might involve comparisons of alternate trip-generation equations or travel-time estimation procedures.

- Multi-Module Internal Validation -- Figure 4b shows a situation in which two or more modules are used to produce alternative emissions or activity estimates using multiple methods and/or data sources. This example might involve assessment of the applicability or sensitivity of different transportation system models for the analysis of possible transportation control measures. Other modules might be involved in this type of analysis, but they would be held static while the three indicated modules (Control Strategies, Transportation Systems and Transportation Activity) would be exercised as data and methods would allow.

- External/"Real World" Validation Exercises -- Figure 4c shows the potential flows for a generic external or "real world" validation exercise. Such an exercise would typically include one or more of the following:

  (1) a set of direct measurements (on-site tailpipe or full-scale laboratory) or remote measurements of vehicle emissions,

(2) ambient measurements (e.g., in a tunnel or garage, along a roadway or around an indirect source), or

(3) measurements/collection of "ground-truth" data on some critical element in the emission estimation process (e.g., actual acceleration rates, vehicle or speed distributions, trip-making behavior, trip reduction program participation).

The three paths in Figure 4c would apply to validation efforts that use the types of measurements listed above.

Few "consumer-level" Applications Models would produce data that could be used as direct comparisons to measurements which are actually possible in the field. Most validation efforts have essentially been "point estimates," performed in only a few specific locations which have very specific characteristics. Even the modeling systems which would be developed for the most localized Applications Models would necessarily be based on aggregate descriptions of driver behavior, transportation system characteristics, etc. This is why a separate type of Applications Model for local-scale validation studies is proposed. Such a model (or alternate models) would be developed from the full array of data and techniques available in the Metamodel which apply to the specific situation in the validation exercise. Additional existing Applications Models could be run in parallel with the site-specific model for comparison purposes. Since the site-specific model might not have parallel methods, data or structure to the other Applications Models, one of the most important stages of this type of validation exercise would be determining how to generalize the conclusions to the rest of the modeling system. This would be done by determining how the validation exercise reflects on individual elements of the Metamodel, identifying improvements that can be made to Metamodel methods and data, and then examining all existing Applications Models to determine the utility of changes to "consumer-level" models.

IMPLEMENTATION OF THE METAMODEL/APPLICATIONS MODEL CONCEPT

A number of possibilities exist for implementation of the concept described in this proposal. As a practical matter, the development of the Metamodel and Applications Models would best be performed by one organization which could also perform and coordinate related research as well as providing support functions for users of both model sets. Either the EPA Office of Mobile Sources or Office of Research and Development could undertake this effort. As an alternative, EPA funding and funding from industry could be provided to an independent organization which could be created or enlisted for this role. A Center for Research in Transportation and the Environment could be created as a free-standing entity or could be affiliated with a group such as the U.S. DOT Transportation Systems Center in Cambridge or the Institute for Transportation Research and Education (a multi-state institute affiliated with the University of North Carolina).

The basic mission described in this conceptual design could involve a staff of at least ten to twenty technical and data processing professionals beyond those currently engaged in related work at OMS, ORD, the California Air Resources Board and other agencies. If this staff were also involved in research and other functions, additional personnel would be required. The most critical area in personnel and activity requirements would be the level of support provided by OMS and how the current emissions data analysis and inventory-related functions could be divided if the models were not developed and maintained directly by OMS.

While efforts at the level described here may appear to be a major increment to the current activities in this area, there are some specific aspects that should be taken into account:

- Research and regulation in this area are currently experiencing a major increase in investment and activity due to Clean Air Act initiatives and technology-forcing provisions. The effective coordination, assessment and dissemination of research results will require similar increases in effort, and the framework proposed here would be an ideal way to accommodate such rapid growth in a highly specialized technical area.

- Specific aspects of the proposed Metamodel framework, such as development of simpler and better-integrated Applications Models and maintenance of databases for access by researchers and Applications Model users, will actually reduce the time and effort required to perform the more conventional and widely performed types of highway vehicle inventories.

FIGURE 1. PROPOSED FRAMEWORK FOR HIGHWAY VEHICLE EMISSION INVENTORY METHODOLOGY DEVELOPMENT

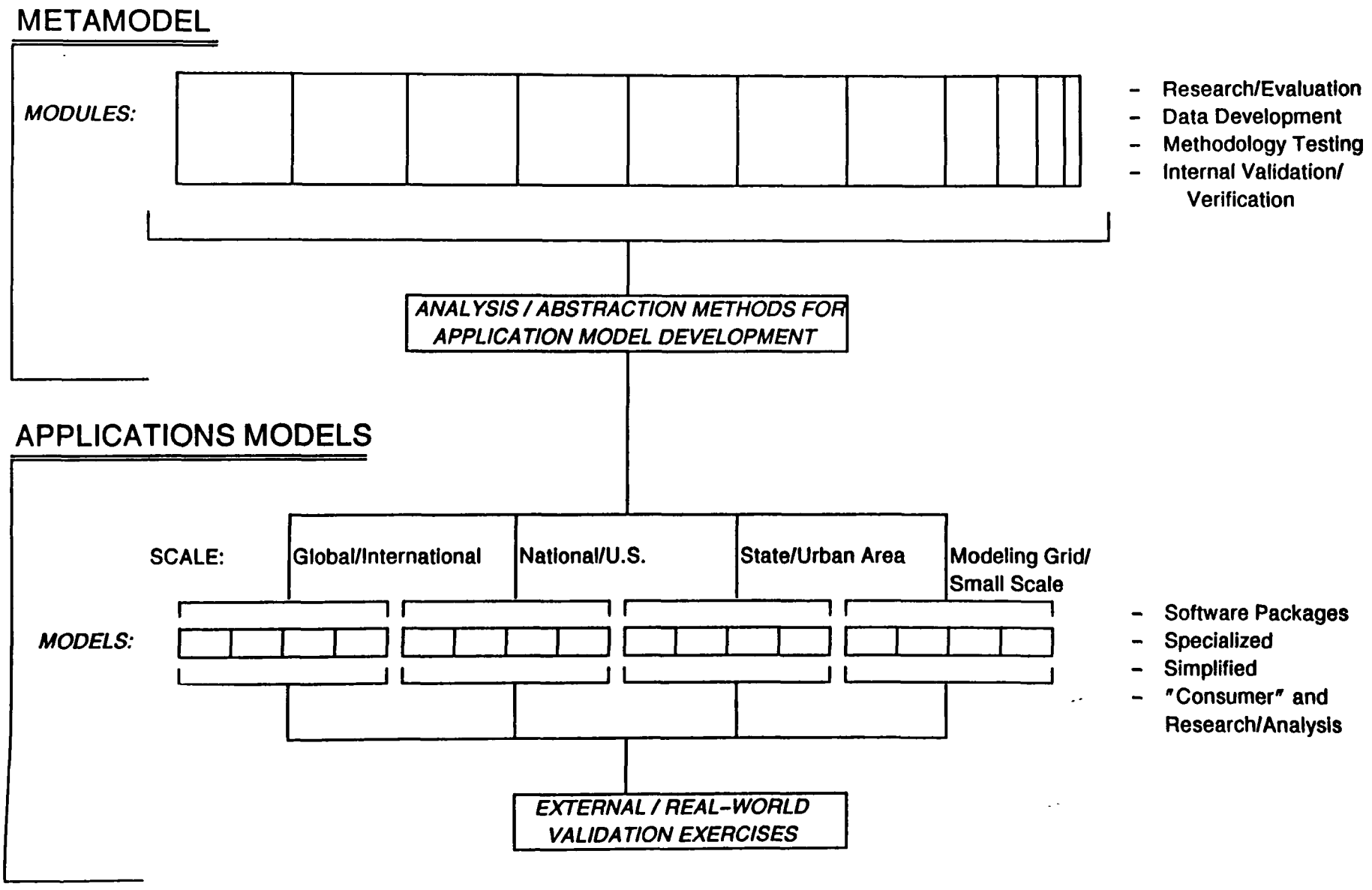


FIGURE 2. METAMODEL MODULES

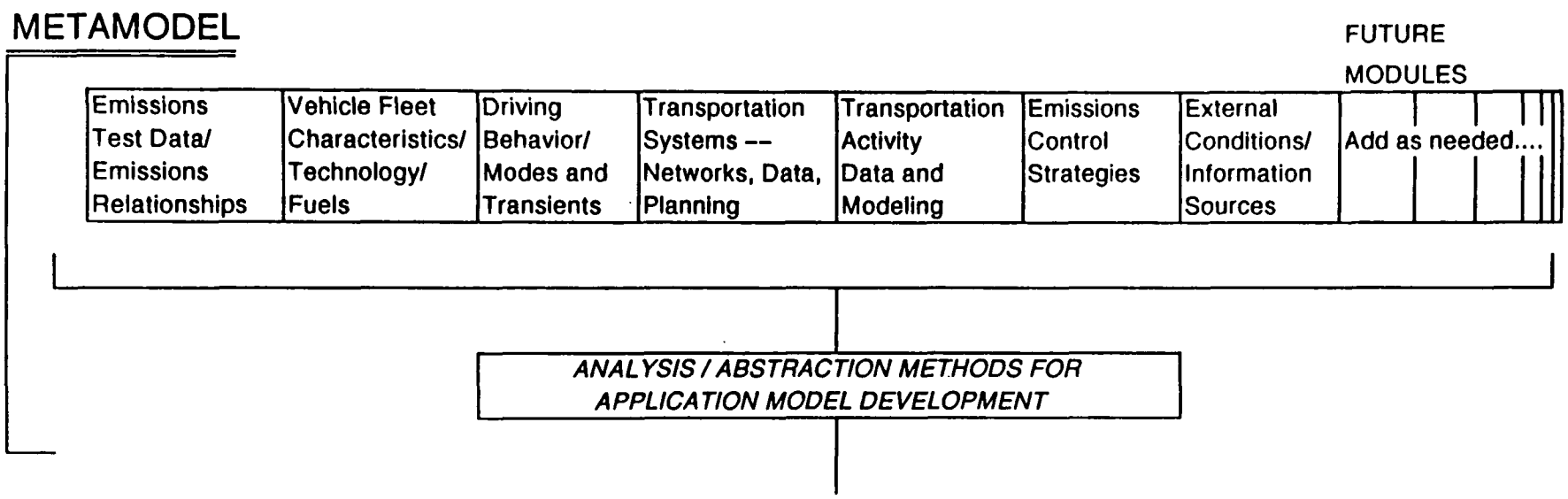


FIGURE 3. POTENTIAL APPLICATIONS MODELS FOR HIGHWAY VEHICLE EMISSION INVENTORIES

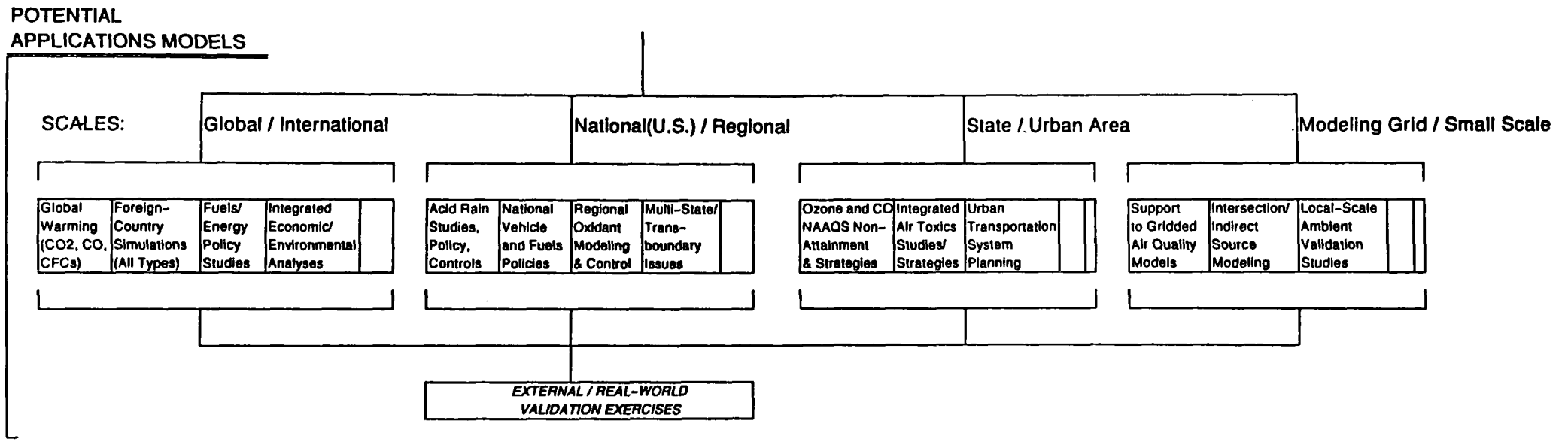


FIGURE 4a. VALIDATION APPROACHES FOR HIGHWAY VEHICLE EMISSION INVENTORY METHODS -- Within Modules

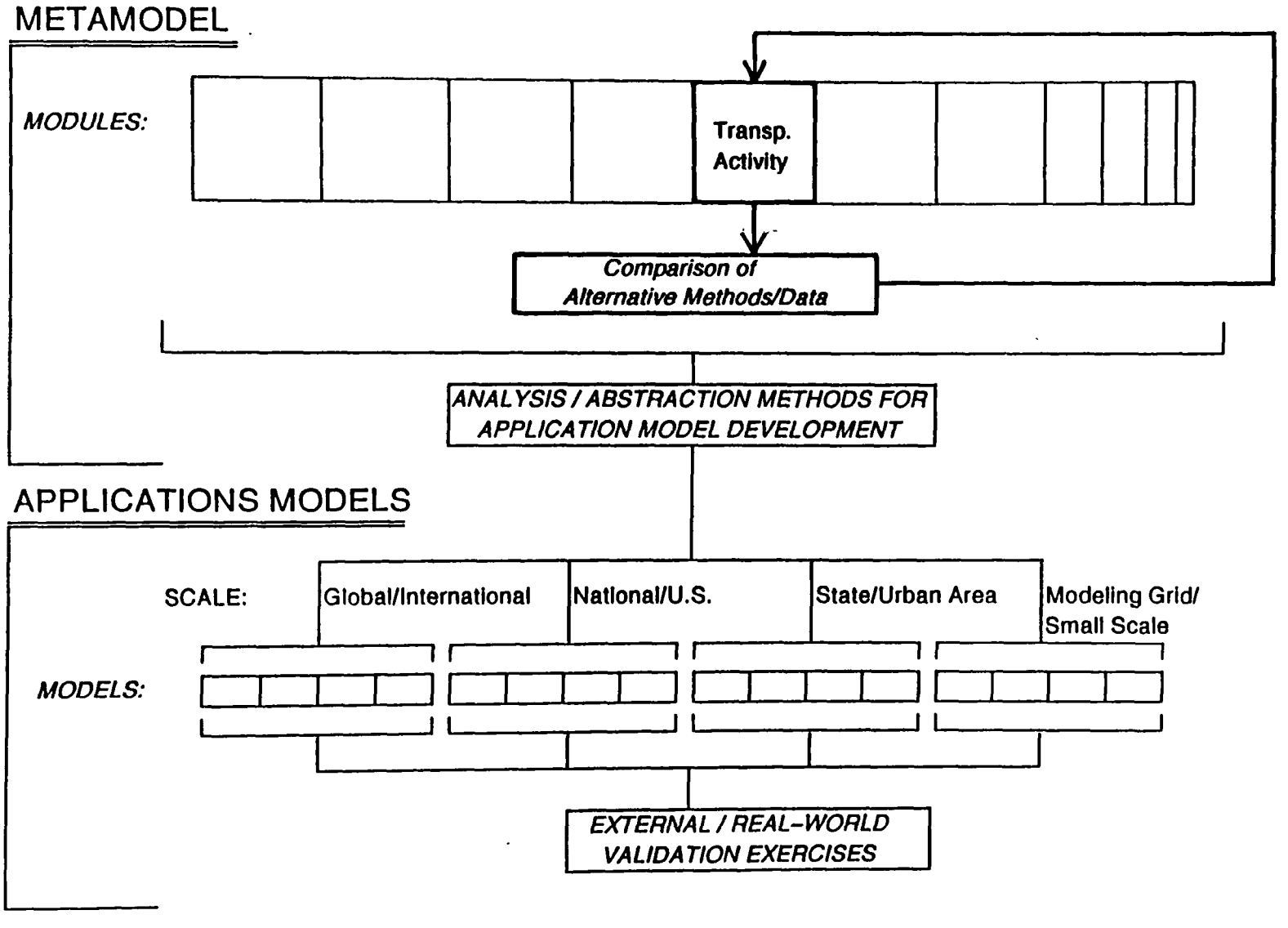


FIGURE 4b. VALIDATION APPROACHES FOR HIGHWAY VEHICLE EMISSION INVENTORY METHODS -- Multi-Module Internal Validation

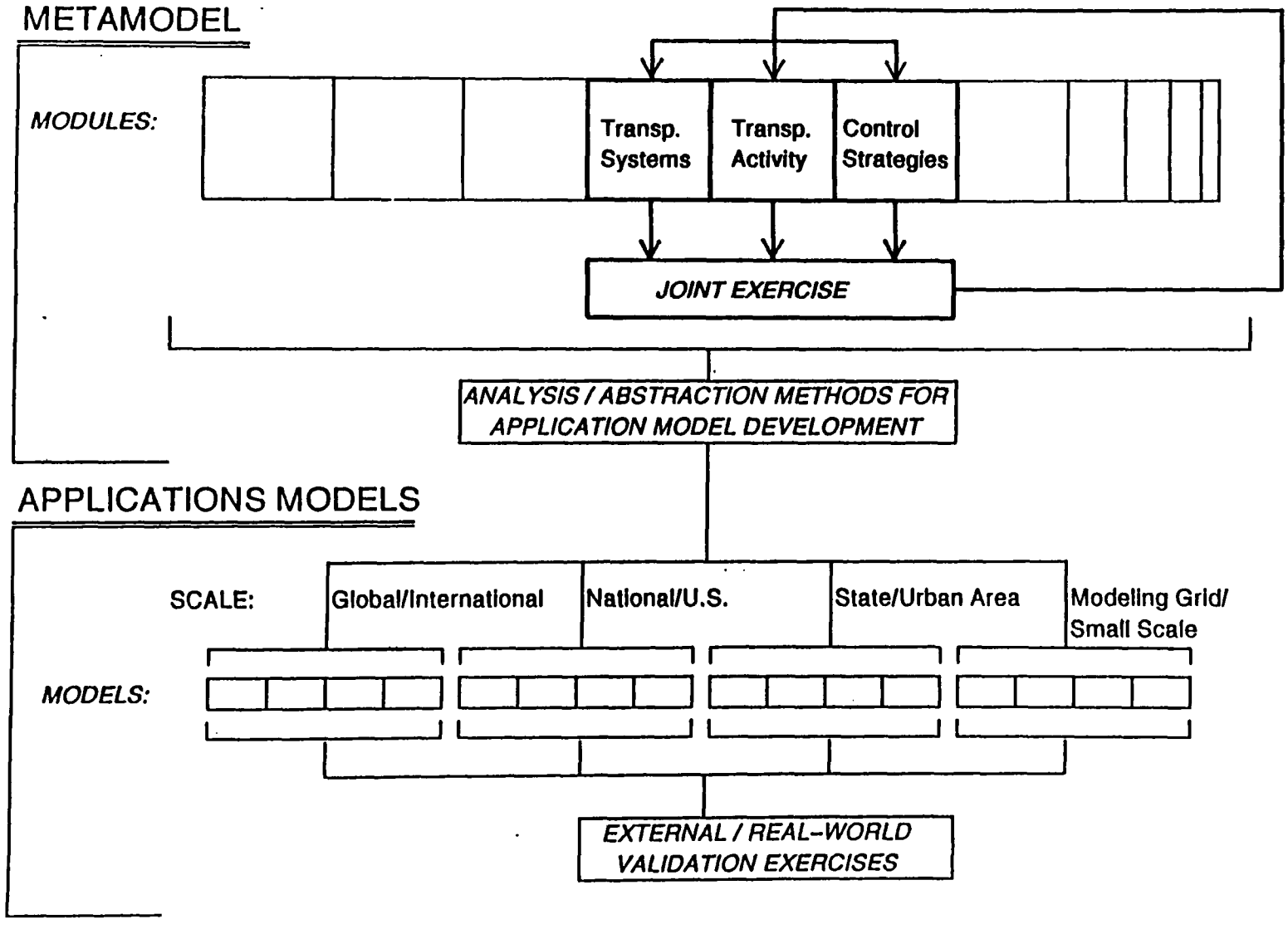
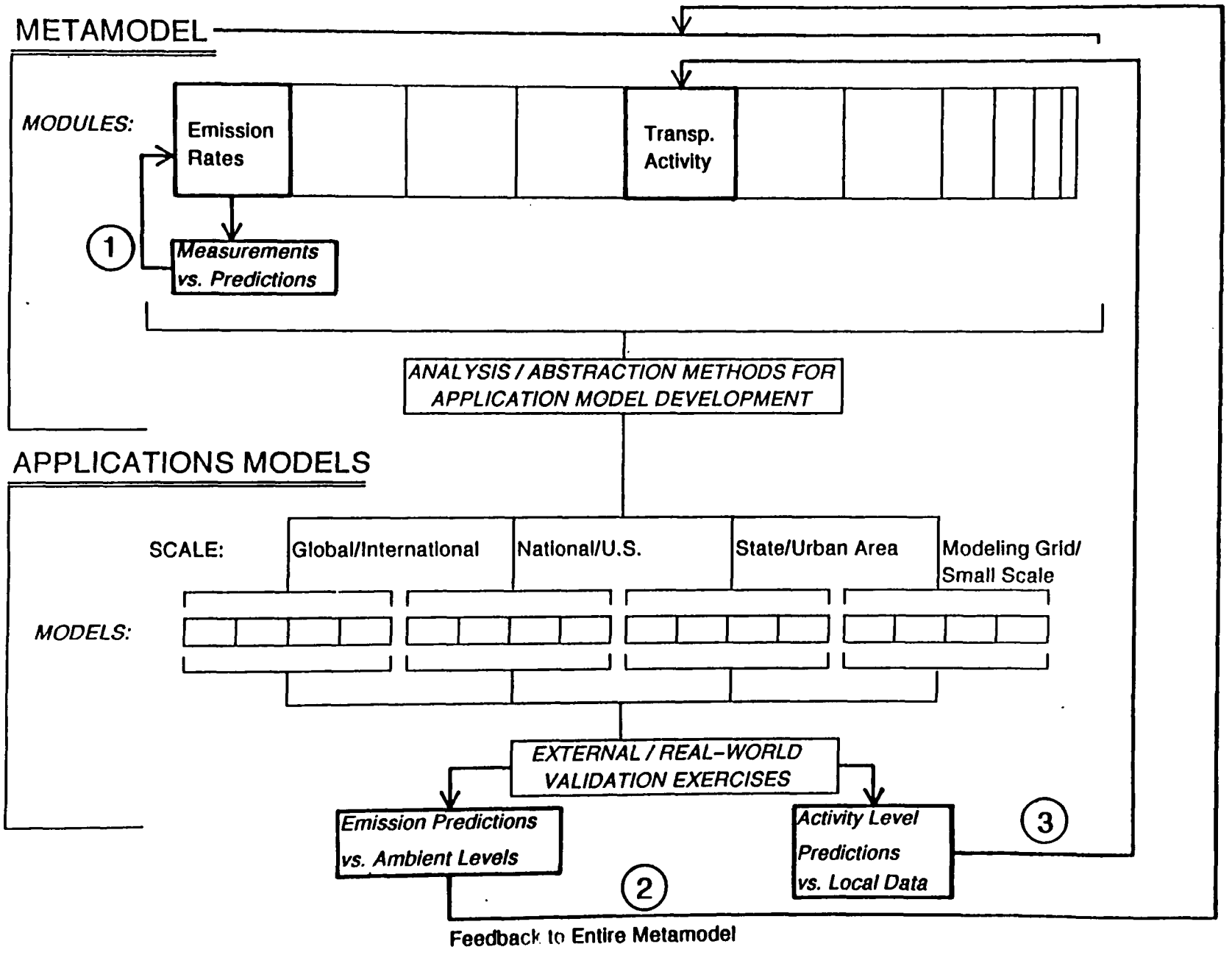


FIGURE 4c. VALIDATION APPROACHES FOR HIGHWAY VEHICLE EMISSION INVENTORY METHODS -- External Validation Exercises



ATTACHMENT A:

SELECTED REFERENCES FOR HIGHWAY VEHICLE EMISSION ESTIMATION

TRANSPORTATION PLANNING AND NETWORK MODELING

1. *Characteristics of Urban Transportation Systems.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., October 1985.

   The document provides a source of data on the most important characteristics of urban transportation systems. The document assesses only the supply or performance characteristics of urban transportation systems. Chapter 4 contains a set of quantitative values for selected supply parameters used to characterize automobile-highway systems (i.e. auto and truck traffic): speed, capacity, operating cost, energy consumption, pollutant emissions, capital cost, and accident frequency.

2. *Characteristics of Urban Transportation Demand, An Update.* Report prepared by Charles River Associates, Inc. for Urban Mass Transportation Administration, Contract No. DOT-T-88-18, Washington, D.C., July 1988.

   The report presents a selection of updated data on a wide variety of statistics pertaining to urban travel demand. The information supplements earlier data contained in the UMTA handbook, *Characteristics of Urban Transportation Demand – A Handbook for Transit Planners.* The report is designed to be used by transportation analysts as a source of data to check the validity of local forecasts developed from traditional planning studies or as a cross-check on the similarity of travel statistics from one locality to another. Certain data also may be used as default values for modeling purposes, when such information is not available locally or would require new or extensive data collection efforts. Much of the information presented was obtained from reports, documents, and memoranda produced by or for each study area contacted. A main criterion of the study was that the information collected be based on surveys, measurements, counts, etc., and not be synthesized results from analytical modeling efforts.

3. *UTPS Highway Network Development Guide.* Report prepared by Cosmis Corporation for the Federal Highway Administration, Washington, D.C. January 1983.

   The purpose of the report is to aid the transportation planner in highway network analysis. The tools for analysis described here are the UTPS programs HNET and UROAD. The report is divided into five sections. The first section describes the link and node components of a network and the characteristics of links and nodes. The UTPS guide is both a user's guide manual to UTPS software and an overview of network development , planning, and analysis techniques. Chapter 2 describes how UTPS highway network data may be applied to short-term and long-term travel forecasting, traffic assignment, and related highway system evaluation. Chapter 3 examines specific assessment methods. A discussion of impedance follows with comments on speed-capacity options. Data cover default values of speed and capacity by area type and facility type. The final section describes methods of network evaluation.

4. *Highway Capacity Manual: Special Report 209.* Transportation Research Board, National Research Council, Washington, D.C., 1985

The document is a guide to the design and operational analysis of highway facilities. The 14 chapters represent revision and updates of material contained in earlier editions, and new material reflecting the many changes in the characteristics of travel and in the information needed to conduct highway capacity analyses. Chapter 2, traffic characteristics, presents and discusses values observed throughout North America for many of the parameters and variables introduced herein. Chapters 3 to 8 cover uninterrupted flow facilities. Chapter 9 to 14 focus on interrupted flow facilities and their components.

5. *Highway Performance Monitoring System, Analytical Process: Volume II-Version 2.1 Technical Manual.* U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., December, 1987.

The report was developed by FHWA to analyze data furnished by the individual states. These analyses cover the arterial and collector functional systems, and the HPMS data are obtained from sample highway sections representing those systems. The results of these analyses are used by the FHWA for many purposes, including policy development and the biennial reports to the Congress on the status and performance of the Nation's highways. The Manual covers the technical aspects of the Analytical Process including an explanation of the methodology used in the models that comprise this process, the formulas used, and the values of various tables included in the programs such as minimum tolerable conditions, design standards, and improvement costs. Actual use of this process is explained in *Volume III - User's Guide.*

The section on impact analysis provides a comparison of vehicle performance measures under various scenarios. Among those scenarios are average overall travel speed. Overall average travel speed is obtained from initial speed adjusted for different factors. Appendix D includes tables on vehicle fuel consumption for 7 vehicle types stratified by speed and grade. Appendix H includes tables on excess fuel consumption incurred because of speed change cycles, for 7 vehicle types.

6. *Highway Performance Monitoring System Analytical Process: Volume III, Version 2.1 User's Guide.* Federal Highway Administration, Washington, D.C., December 1987.

The manual provides guidance for reporting HPMS data and to establish updating procedures for the annual submission. The manual outlines procedures for reporting 3 types of data: areawide, sample, and universe mileage data. Areawide data is a data base of information reported annually for rural, total small urban, and individual urbanized areas. It consists of totals for mileage, local system data, travel activity by vehicle type, and other statistics. Sample data include specific inventory, condition and operational data obtained for the sample panel of highway sections. These data will be expanded to represent the universe of highway mileage, permitting the evaluation of the performance of various highway systems. Universe mileage data include a complete inventory of mileage classified by system, jurisdiction and selected operational characteristics.

7. *Traffic Monitoring Guide.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., June 1985.

Section 2 of the guide discusses the structure of traffic characteristics monitoring; how traffic counting, vehicle classification, and truck weighting relate to the overall monitoring effort. In Section 3, traffic counting is discussed. The chapter focuses on the development of the statistical scheme. The sample is critical to both the reliability of information on traffic volumes and to the later development of samples for vehicle classification and vehicle weighting. Chapter 4 covers vehicle classification. This section includes aspects of sample development pertinent to obtaining vehicle classification information along with a description of the fhwa vehicle categories. Section 5 covers truck weighting and contains information on collection and summarizing data obtained at truck weight sites.

8. *Guide to Urban Traffic Volume Counting.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., September 1981.

This report presents methods by which urbanized areas can develop and implement integrated traffic counting programs to serve the volume data needs of all agencies. Methods for estimating volumes at a single location, volumes across a cordon line, VMT within a corridor or other small area, and regional VMT are presented. Sound statistical sampling concepts permit the collection of data at predetermined levels of precision and in a cost-effective manner.

9. *Guide for Estimating Urban Vehicle Classification and Occupancy.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., September 1980.

The manual provides sampling and data collection procedures for field surveys that estimate vehicle classification and occupancy and (when combined with estimates of vmt from parallel mechanical traffic counting programs) that estimate travel by vehicle type and personal travel. Because sound statistical techniques are used, these surveys can provide valid estimates at predetermined levels of precision and in a cost-effective manner.

10. *Highway Functional Classification: A Management Tool.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., November 1982.

This report is concerned with functional classification as a highway system management tool utilized by Federal, State, and local governments. It includes a brief history, the concepts, system characteristics, and federal and state uses of functional classification. The report mentions the experiences of several states to present a broad range of applications of functional classification in state planning efforts, with detailed review in the cases of Washington and Wyoming.

TRANSPORTATION DATA SOURCES

1. Rudman, M. Leon. *Vehicle Miles Traveled: An Evaluation of Existing Data Sources.* U.S. Department of Transportation, Energy Program Division, presented to the Transportation Research Board, Washington, D.C., January 1979.

   This relatively old report evaluates data sources for VMT and gasoline fuel consumption. Collection, reporting, and estimation procedures are addressed. Since direct measurement of VMT has never been made, the available information consists of indirect estimates based on various sets of assumptions. Since the 1973 energy crisis, FHWA has requested the states to estimate VMT based on average fuel efficiency rates for different vehicle classifications. The FHWA has not developed and selected one methodology to estimate VMT. The paper discusses NPTS data, the Claffey model, and the RDTRAV computer program, as well as data in *Highway Statistics*.

2. *Highway Statistics*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., Annual Series.

   This publication brings together annual series of selected statistical tabulation relating to highway transportation in the areas of highway use, finance, and performance. Of special interest are tables on state vehicle registration, annual VMT by highway category, vehicle types, functional system, fuel, and speed data.

3. *Census Data and Urban Transportation Planning in the 1980s.* Transportation Research Record 981, Transportation Research Board, Washington, D.C., 1984.

   This issue of the *Transportation Research Record* includes a number of papers that deal with several aspects of the transportation planning process: 1) the use of the 1980 Census for transportation purposes; 2) the Urban Transportation Planning Package, which is a special product of the 1980 Census specifically tailored for transportation planning; 3) an outline of several methods for using the UTPP, such as processing its output on microcomputers; 4) applying and supplementing census data for transportation planning; and 5) experience with the Urban Transportation Planning process in the Delaware valley region, Colorado, and New York.

4. *Proceedings of the National Conference on Decennial Census Data for Transportation Planning.* Special Report 206, Transportation Research Board, Washington, D.C., December 1984.

5. *Journey-to-Work Trends: Based on 1960, 1970, and 1980 Decennial Censuses.* Report prepared by the Office of Highway Information Management, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., July 1986.

   This report identifies the changes which have occurred in population, journey-to-work patterns, mode of travel to work, and vehicle availability, at the household level in the largest metropolitan areas of the U.S. between 1970 and 1980. The report is based on U.S. Bureau of Census data, and it includes some limited analysis of changes since 1960. Selected census information for 1960, 1970, and 1980 was summarized from available census computer data sets, and, to a very limited extent from census publications, to a

geographic base which was compatible for the three decennial years. Chapter 1 contains the purpose, scope, and limitations of the study. Chapter 2 summarizes population and other census data for the nation as a whole. Chapter 3 looks at population data for the large metropolitan areas while Chapters 4 and 5 focus on workers. Chapter 6 identifies changes in mode of travel to work, and Chapter 7 addresses vehicle availability. Chapter 8 completes the report by referencing the latest available population estimates to evaluate what has occurred since 1980.

6. *Nationwide Personal Transportation Study, Volume II.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., November 1986.

The Nationwide Personal Transportation Study (NPTS) is an investigation of the characteristics and personal travel patterns of the U.S. population. The NPTS derives its information from a nationwide home interview survey of households. The NPTS is a unique source of information on personal travel, both as a reference on key travel measures such as trip rates and vehicle occupancy levels, as well as being a source for linking the characteristics of households with their travel by all modes of transportation.

This is the Volume II of a two-part report which presents findings from the 1983-1984 NPTS survey. The survey obtained data from a national sample of 6,438 households. Previous NPTS surveys were conducted in 1977 and 1969. Comparing results from these three surveys provides a good picture of how the country's population and travel habits have changed over time.

This report examines drivers and their travel, vehicle trips and travel, person trips and travel, workers and their journey to work, vehicle occupancy, characteristics of travel period trips and travel and the use of vehicle safety devices. The various subject matters are explored relative to household location, income, vehicle ownership, and other socio-demographic attributes of the household. In addition, trends are evaluated over time.

7. *Household Vehicles Energy Consumption, 1988.* U. S. Department of Energy, Report No. DOE/EIA-0464(88), Washington, D.C., February 1990.

This report is a descriptive profile of personal vehicle transportation in the residential sector. It is based on data from the 1988 Residential Transportation Energy Consumption Survey (RTECS). The survey was designed to collect data on actual VMT for each vehicle in the household, information on vehicle characteristics, number and type, and vehicle fuel efficiencies, consumption and expenditures.

8. *National Travel Survey: Travel During 1977.* Census of Transportation, U.S. Department of Commerce, Bureau of the Census, Washington, D.C., October 1979, and 1977 NTS Public-Use Tape.

9. *National Vehicle Population Profile Data Tape.* R.L. Polk and Company, Detroit, MI. (Annual)

Polk data tapes provide county-level data (for the fifty states) on vehicle registration for eight different weight classes. The tapes also provide data on vehicle age and engine size for the eight vehicle classes.

10. *Truck Inventory and Use Survey*. Bureau of the Census, U.S. Department of Commerce, public use tape modified and expanded by Systems Design Concepts, Inc., for Federal Highway Administration, Washington, D.C., May 1982.

REVIEW OF DATA AVAILABLE FROM SELECTED TRANSPORTATION DATA SOURCES

1. *Highway Statistics (Annual).* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Highway Statistics includes statistics for the following:

•State motor vehicles registrations: total, automobiles, buses, truck tractors, light trucks, trailers, semi-trailers

•Total state public road and street mileage classified by functional system

•National Network Mileage for trucks

•Annual vehicle miles of travel by state and functional system

- Nationwide fuel consumption by vehicle type, average annual vehicle miles of travel, average miles traveled per gallon of fuel, and average fuel consumption in gallons for each vehicle type

2. *1987 Census of Transportation: Transportation Inventory and Use Survey (Quinquennial).* Bureau of the Census, U.S. Department of Commerce, Washington, D.C.

The *Transportation Inventory and Use Survey* (TIUS) is a sample survey of private trucks registered in each state, stratified by truck type. Truck types for sample stratification include pickup, van, single-unit light, single-unit heavy, and truck tractors.

The TIUS includes data on the following:

- Operating characteristics including annual miles, range and base, miles travelled outside state of registrations
- Vehicle characteristics including size, average weight, engine size
- Energy use including type of fuel used, and miles per gallon

3. *Motorcycle Statistical (Annual).* Motorcycle Industry Council, Research and Statistics Department, Irvine, CA.

Motorcycle Statistical is an annual report on motorcycle market and usage. It includes registrations, penetration by region, and mileage by state (on- and off-highways).

4. *National Vehicle Population Profile Data Tapes (Annual).* R. L. Polk and Company, Detroit, MI.

Polk data tapes provide county-level data (for the fifty states) on vehicle registration for eight different weight classes. The tapes also provide data on vehicle age and engine size for the eight vehicle classes. These data are collected from registration data maintained by state Motor Vehicle Departments. Availability of data directly from state sources varies.

5. The Urban Transportation Planning (UTP) Process

The purpose of the UTP process is to provide guidance for the development, evaluation, and implementation of alternative transportation planning proposals. It consists of developing a zone system, selecting links, trip generation, trip distribution, modal split, and traffic assignment. Output from UTP-type computer models include estimation of the number of trips to and from activity centers in the area of analysis, orientation and magnitude of traffic volumes, determination of the magnitude of travel by mode, VMT, and speed.

There are important limitations associated with existing UTP computer models. For example, VMT generated by non-coded facilities (i.e. residential streets) are not accounted for. In addition, UTP-type models only simulate daily and peak period volumes with no consideration for seasonal variation in volumes. Finally, speeds developed through UTP models serve more as a means of allocating trips to balance the network than a reliable output.

6. *Highway Performance Monitoring System Analytical Process.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., December 1987.

The purpose of the Highway Performance Monitoring System (HPMS) is to provide a procedure by which the nation's functional system of highways can be analyzed based on data annually sampled by all states. HPMS is composed of two major components: data collection and analytical process. The analytical process analyzes data for each highway section and expands the results to represent each functional system. Data reported include of highway mileage, daily vehicle miles of travel, land area, population, and travel activity by vehicle type.

HPMS includes:

- Estimates of daily vehicle miles of travel (DVMT) by functional system are to be prepared for rural, small urban, and individual urbanized areas of the State on an annual basis. HPMS disaggregates VMT to twelve discrete daily units based on levels of congestion.

- Development of HPMS estimates of highway travel by functional system are to be derived using count-based traffic data.

- HPMS determines an overall average travel speed for different congestion levels. An initial running speed is estimated which is then adjusted for pavement conditions, curves grades, stop cycles, and idling time.

- HPMS does not include a module that could estimate local road operating characteristics.

7. Urban Traffic Volume Counting

Vehicle count procedures assume that the VMT in a state during a year can be estimated by counting the traffic on representative sections of roadways during short periods of time and expanding these results to statewide totals.

Traffic counting programs are expensive to implement. As such, they tend often to focus on particular needs of an agency which makes estimates of regional travel often incomplete. In addition, vehicle speeds and vehicle classifications are not addressed in a counting program.

8. *Nationwide Personal Transportation Study*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., November 1986

The *Nationwide Personal Transportation Study* (NPTS) is an investigation of the characteristics and personal travel patterns of the U.S. population. The NPTS emphasizes the relationship between demographic and economic characteristics and automobile travel. The relevant factors in estimating VMT include number of cars per household, trip origins and destinations, urban versus rural travel, and vehicle age.

NPTS tabulates the distributions of VMT by trip purpose and household vehicle ownership, trip distance, number of occupants, day of week and time of day. In the "Worker and Work-to-Journey" component of NPTS, average commute length and commute time by urbanized area size are reported. Those may be used as a very coarse representation of "average" commute speed. Commute time is measured "door to door" which includes walk access time in addition to in-vehicle time.

The NPTS has limitations in estimating VMT. First, it is not known how accurate individuals are in estimating their VMT. Second, no data are collected on existing fuel prices, which prevents accurate estimates of cost of travel. Third, the published NPTS report does not reveal geographic locations of the respondents, therefore it is impossible to relate annual VMT per household to the special characteristics of the region of residence . Fourth, NPTS is representative of personal travel at the national level, and therefore, is of limited use at the local and state levels. Fifth, NPTS does not evaluate operating characteristics such as average annual daily traffic, volume, speeds, or capacity.

9. *Household Vehicles Energy Consumption, 1988*. U.S. Department of Energy, DOE/EIA-0464(88), Washington, D.C., February 1990.

The *1988 Household Vehicles Energy Consumption* report is a descriptive profile of personal vehicle transportation in the residential sector. It is based on data from the 1988 Residential Transportation Energy Consumption Survey (RTECS). The survey was designed to collect data on actual VMT for each vehicle in the household, information on vehicle characteristics, number and type, and vehicle fuel efficiencies, consumption and expenditures.

In the RTECS, annual VMT for a vehicle were either calculated using two odometer readings or imputed using a regression estimate. For a sample vehicle, beginning-of-year and end-of-year

odometer readings were collected. If two odometer readings were available, the difference between the two readings (adjusted to a standard annualized VMT) equaled the VMT. In the second step, the annualized VMT was adjusted to correspond to the time period that a vehicle was in possession by the sample household.

For vehicles with less than two odometer readings, a multiple regression analysis was used to estimate the annual mileage, where the number of drivers, household income, age of household head, type of vehicle, and use of vehicle on the job were all included as explanatory variables. The regression model resulted in estimates of annualized VMT. These VMT are then adjusted to correspond with the time the vehicle was in possession of the household.

10. *The Urban Transportation Planning Package* (Transportation-Related Data from the Decennial Census)

The *Urban Transportation Planning Package* (UTPP) of the Census contains information on the journey-to-work. The information was collected from responses to the long-form census questionnaire sent to one sixth of the households. However, only half of these were actually coded resulting in a sample of about 8.33 percent of all households.

The survey collected data on the distance from home to work, travel time, departure time, and the principal mean of transportation to work. Questions assumed direct trips from residence to the work place and did not request information about indirect work trips or trips to second jobs.

Travel times reported are for the total number of minutes that usually takes the respondent to get from home to work including time spent waiting for public transportation or picking up passengers on the way to work. Time-of-day travel data were not collected but obtained by converting the census data into estimates of peak-hour travel.

The census collected data on only one mode of travel, the one used for most of the trip. No consideration is given for trips in which a combination of modes is used. In addition, the survey does not include trucks weighting more than one ton as a means of transportation.

11. *State Transportation Reports*. Various State transportation agencies and metropolitan planning organizations.

Most States and some metropolitan areas publish annual reports of vehicle miles travelled, traffic flows and counts and other data developed for transportation planning and engineering. These data are often the basis for HPMS and *Highway Statistics*, and are usually more disaggregated and better suited for emission inventory applications. More detailed data may be available directly from these agencies.

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U.S. "GeoData"
Digital Cartographic and Geographical Data

- The U.S. Geological Survey is in the process of preparing digital data for the entire country, but coverage is currently very sparse for data corresponding to smaller-scale maps. Catalogs, indices to available data and price lists are available from USGS (703/860-6045).

- Four basic types of data are available:

  - Digital Elevation Models (basic topographic information)

  - Digital Line Graphs (planimetric [line map] information for USGS maps). These include transportation systems, as detailed below.

  - Geographic Names Information System

  - Land Use and Land Cover

- Planimetric Digital Data consists of digitized line graphs (DGLs) at the 1:24,000 (7.5 minute) and larger scales. It is digitized and sold in four thematic layers:

  - Boundaries

  - Transportation, including (1) roads and trails, (2) railroads and (3) pipelines and transmission lines

  - Hydrography

  - U.S. Public Land Survey System

- Land Use and Land Cover maps are available at the 1:100,000 and 1:250,000 scales. Data can be formatted either as a set of polygons which consist of lines enclosing areas with specific characteristics (e.g. a particular land use) or as in a grid cell format which uses 10-acre grid cells as the areal unit. Categories of data are:

  - Urban or built-up land
  - Agricultural land
  - Rangeland
  - Forest land
  - Water areas
  - Wetlands
  - Barren land
  - Tundra
  - Perennial snow or ice

  Each major class is divided into further categories.

- Suitable for use in GIS systems for spatial analyses and geographic studies
- Can be used for calculations such as total lengths of highways in an area or in specific sub-areas
- Can be combined with other types of digital data, such as U.S. Census Bureau population files
- Available in compact disc-read only memory (CD-ROM) as well as magnetic tape.

APPENDIX B

A CONCEPTUAL DESIGN FOR A NEW HIGHWAY VEHICLE EMISSIONS ESTIMATION METHODOLOGY

June 14, 1991

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ABSTRACT

Mobile source emissions estimates used throughout the U.S. for developing air pollution abatement strategies may underestimated by as much as a factor of two or more for both hydrocarbons (HC) and carbon monoxide (CO). Since motor vehicles are the dominant source of these species in many non-attainment areas, such large errors make determination of appropriate abatement strategies difficult and prone to error. In addition, current mobile source emissions factor models are not user-friendly or designed to evaluate the impact of reformulated fuels, new technologies, and new control strategies.

The perspective taken in this document to address these deficiencies is based on the experiences of the authors in evaluating and applying motor vehicle emissions models in non-attainment areas. This perspective is somewhat limited since the primary emphasis has been on the emissions rate sub-model of the modeling system used in constructing the mobile source contribution to the inventory.

Weaknesses in the components used to construct motor vehicle emissions models are described and potential improvements identified. In particular, limitations in the emissions rate sub-model are addressed and areas for improvement in future models were noted. An experimental protocol for performing on-road validation of the model is described.

By concentrating on improving model inputs rather than developing new models, costs can be minimized. Periodic on-road validation tests would, however, be required to verify assumptions and data acquisition methods.

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1.0 INTRODUCTION

Mobile source emissions inventory estimates used by both the U.S. EPA and state and local agencies for developing air pollution abatement strategies may, as described in the work assignment for this report, be underestimated by as much as a factor of two or more for both hydrocarbons (HC) and carbon monoxide (CO). Since motor vehicles are the dominant source of these species in many non-attainment areas, such large errors make determination of appropriate abatement strategies difficult and prone to error. In addition, current mobile source emission factor models were not originally designed to evaluate the impact of reformulated fuels, new technologies, and new control strategies on HC, CO, NO_x and other species (e.g., PM_{10} and speciated organics), thus hampering projection capabilities over the next 5 to 10 years.

The perspective taken in this document to address these deficiencies is based on the experiences of the authors in evaluating (Pierson, 1989; Pierson et al., 1990; Gertler et al., 1991; Gertler and Pierson, 1991) and applying (Watson et al., 1990; Chow et al., 1991) motor vehicle emissions models in non-attainment areas. This perspective is somewhat limited since the primary emphasis has been on the emissions rate sub-model of the modeling system used in constructing the mobile source contribution to the inventory. It is our belief, however, that this component is crucial if we are to develop a motor vehicle emissions model for the Year 2000.

1.1 Background

In order to calculate automotive emissions factors during the Southern California Air Quality Study (SCAQS) (Lawson, 1990), the Southwest Research Institute (SwRI) conducted a study, sponsored by the Coordinating Research Council (CRC), designed to obtain emissions factors in an on-road setting (Ingalls et al., 1989; Ingalls and Smith, 1990). The experimental approach was to measure air pollutant concentrations into and out of a roadway tunnel located in Van Nuys, CA. Air displacement measurements were taken to calculate, using in-out concentration differences and air flow, the amount of each pollutant emitted. Division by the vehicle-miles logged by traffic in the tunnel during the measurement yielded the traffic-average emissions rate per vehicle (grams per vehicle-mile) during the measurement.

The carbon monoxide (CO) and hydrocarbon (HC) emissions factors derived by this *in-situ* method were far higher than those predicted by the California Air Resources Board's (ARB's) emissions factor model EMFAC. The average ratios of tunnel emissions factors to EMFAC7C (version 7C of EMFAC) emissions factors were: 1) 2.7 ± 0.7 for CO; 2) 4.0 ± 1.5 for HC; and 3) 1.02 ± 0.21 for NO_x (nitrogen oxides) (Pierson et al., 1990). These differences between measured and modeled emissions rates raised substantial concern regarding the validity of the *in-situ* measurement, the vehicle emissions modeling procedure, the model inputs, and the current vehicle emissions inventories, and automotive pollutant abatement strategies.

In response to these questions, the Desert Research Institute (DRI) conducted a preliminary evaluation of the tunnel experiment at the request of CRC (Pierson, 1989). The evaluation did not identify any deficiencies sufficient to invalidate the tunnel experiment or to account for the discrepancies with the model predictions, especially the discrepancies between experimental and predicted CO/NO_x ratios or HC/NO_x ratios.

Further work was then undertaken at DRI, under CRC sponsorship, to examine the general nature of discrepancies between measurements and models using the SCAQS Tunnel Study as a focal point for this examination. As part of this work, a comparison was made between the

SCAQS Tunnel Study and other on-road studies (Pierson et al., 1990). The conclusion of this phase of the study was that the SCAQS Tunnel Study results were consistent with previous on-road experiments throughout the United States showing CO/NO_x and HC/NO_x ratios higher than dynamometer and model predictions.

An additional evaluation was made of motor vehicle emissions modeling issues (Gertler and Pierson, 1991) and it was concluded that the differences in the ratios of emitted species was due less to limitations in EMFAC and MOBILE than to limitations in the data base used to construct the model input. [As mentioned above, a second, more complex, series of issues not addressed in this work is the limitations in transportation models which use as their input the results from EMFAC or MOBILE.] While these are not the only questions, they appear to be at the heart of the model underpredictions.

These concerns and those of other scientists were subsequently aired at the CRC-APRAC (Air Pollution Research Advisory Committee) Vehicle Emissions Modeling Workshop held at the end of October 1990 in Newport Beach, CA (Cadle, 1991).

1.2 Objectives

The objectives of this report are to:

- Identify the needs for motor vehicle emissions modeling.

  Included in this are: 1) identification of the types of pollutants of interest and an explanation of why and where they are important; and 2) identification of important species not currently addressed by the model (PM_{10} and organic speciation).

- Specify improvements needed in current motor vehicle modeling technology.

  Included are transportation modeling, emissions factor modeling, grid allocation modeling, temporal distribution modeling, and speciation modeling.

- Describe experimental studies and quality assurance activities needed to provide model input data and evaluate model results.

  Included are dynamometer tests, test cycles, smog certification test data, acquisition of test fleets, roadway tests, tunnel tests, roadway verification, and remote exhaust sensing.

  Traffic counts and classification, emissions estimates from independent data bases, uncertainty estimates, and reconciliation methods with on-road and ambient air measurements are also discussed.

1.3 Guide to Report

This first section details the nature of the problem to be addressed and outlines the objectives of the report. Section 2.0 provides a brief description of the components of motor vehicle emissions modeling systems, what data they use, and how they relate to each other, along

with identifying which components will be dealt with in detail. The limitations in emissions rate sub-models are covered in Section 3.0. A conceptual model for a state-of-the-art emissions rate sub-model along with conclusions and additional recommendations are presented in Section 4.0. Section 5.0 contains references to this document.

2.0 COMPONENTS OF MOTOR VEHICLE EMISSIONS MODELING

New emissions modeling systems must be designed with a clear understanding of the purposes to which they will be applied. Motor vehicle emissions inventories are used for several purposes. First, they identify actual and potentially important emitters for regulation and control. Second, they provide a base level against which regulated emissions reductions and projected increases due to population growth can be evaluated. Finally, they are used in combination with air quality models to evaluate the anticipated effects of emissions reductions.

The first purpose of identifying emitters requires the least rigor. Nevertheless, current motor vehicle emissions models do not provide accurate estimates of the relative amounts emitted by different vehicle types such as diesel, super-high emitters, and new-model passenger cars. As evidenced in the recent letter by Rubenstein (1991), to estimate the impact of high-emitters required use of a FORTRAN debugger to pull the information out of EMFAC. This is beyond the capabilities of most users.

The second purpose of providing base emissions levels is not met by the current inventory methods. Pierson et al. (1990) demonstrate major differences between on-road ratios of CO and HC to NO_x concentrations in areas dominated by motor vehicle emissions and those estimated from inventory methods. Chow et al. (1991) applied EPA's MOBILE model to transportation information in Phoenix, AZ, and calculated that lead emissions constitute 9% of particulate motor vehicle emissions. This abundance was 50 to 100 times the abundance measured in the exhaust from Arizona's I&M testing facility and in particulate samples taken near heavily traveled roads. Watson et al. (1991) also found major discrepancies between the average wintertime source apportionments of PM_{10} and the ratio of motor vehicle particulate emissions to emissions from other PM_{10} sources. The Phoenix inventory showed geological material contributing over 90% of PM_{10}, while the source apportionment modeling found that its real contribution to the highest PM_{10} was 45 to 50%. The inventory showed motor vehicle exhaust contributing less than 4% of PM_{10}, while source apportionment modeling showed contributions of 35 to 40%. Recent source apportionment studies for hydrocarbons in the South Coast Air Basin (Fujita, 1991) show similar discrepancies between source contribution and emissions rate ratios.

The final purpose of evaluating potential control strategies imposes the most rigorous constraints on the accuracy and precision of an inventory and, if this purpose is attained, the resulting inventory is more than adequate for the first two purposes. Current inventories do not have the necessary spatial, temporal, and chemical resolutions to target the locations, times, and reactivities of emissions reductions. The inclusion of accurate organic speciation is especially important for the evaluation of alternate formulations of transportation fuels and their delivery systems.

To attain the third purpose, current motor vehicle emissions models need to be conceptually improved with respect to: 1) travel demand and vehicle miles traveled estimates (VMT); 2) emissions factors by vehicle type, operating conditions, and meteorology; 3) spatial and temporal allocation of emissions; and 4) chemical speciation for VOCs and PM_{10}. In order to implement these conceptual improvements, more efficient and flexible hardware and software platforms are needed.

2.1 Travel Demand and Vehicle Miles Traveled (VMT)

Travel demand modeling was developed by highway engineers to simulate traffic flows for the evaluation of highway design, speed limits, access controls, and traffic light synchronization. While it serves these purposes well, this type of modeling was never intended for the estimation of air quality emissions. These models divide a complex highway network into segments within which different numbers of trips of different types are generated. These are derived from census data such as: 1) numbers of single-and multiple-family households with 0, 1, or 2+ vehicles; 2) total employment; 3) retail employment; 4) service employment and education; 5) government employment; 6) non-retail employment; 7) other employment; and 8) population (JHK and Associates, 1991). These empirical relationships are generally established by surveys of representative populations and are verified against traffic counts. Depending on the complexity of the model, VMT can be generated by time of day, day of week, and time of day. For example, the Bay Area Metropolitan Transportation Commission, which includes the San Francisco area, makes special provisions for greater tourism in the summertime.

The VMT estimates from these models are usually quite accurate in the aggregate, but they become less accurate as higher resolution is required for spatial and temporal allocation. The VMT are very seldom allocated to vehicle types, which is extremely important for air quality modeling. A state-wide or county-wide distribution of vehicles among light-, medium-, and heavy-duty vehicles is applied to all roadways, at all times of day, for all types of trips. This is clearly inadequate for an accurate estimate of vehicle emissions, since these vary substantially among different vehicle types.

Ideally, traffic demand models would be able to provide VMT for defined vehicle classes along each roadway segment as a function of time. At a minimum, VMT needs to be specific to roadway type. With this, a separate distribution of vehicles can be estimated for each roadway type and a separate emissions factor can be calculated for that type. The distribution of heavy-duty diesels and light-duty passenger cars, and the speeds at which they travel, are much different for: 1) expressways; 2) freeways; 3) arterials; 4) arterials-2; 5) collectors; and 6) centroid connectors. The VMT on each of these should be kept separately within the EMS so that a specific vehicle exhaust emissions factor can be applied to each one.

2.2 Emissions Rates

For motor vehicle exhaust, either California's EMFAC7, EPA's MOBILE3, or EPA's MOBILE4 (Seitz, 1989, describes the similarities and differences of these models) have been used to estimate motor vehicle exhaust. These models group vehicles by weight, fuel type (diesel or gasoline), and model year. They then assign grams/mile (EPA models) or grams/second (California models) emissions rates for different vehicle speeds. Options are included to modify these emissions with respect to control device tampering and the effectiveness of inspection and maintenance programs. These models use area-wide (county or state) vehicle registrations to determine the distribution of model year, fuel use, and weight class. Emissions from each category of vehicle are derived from laboratory dynamometer tests of vehicles within each class operating according to the Federal Test Procedure (FTP).

Ingalls (1989) showed on-road emissions of hydrocarbons and carbon monoxide (CO) which were significantly larger than those calculated by these emissions models. Pierson et al. (1990) showed that these results were consistent with observations from other on-road studies, and that they could not be dismissed as an indicator that models might be wrong. Further

evidence using remote sensing of individual tailpipe emissions for CO (Stedman, 1989; Bishop et al., 1989; Bishop and Stedman, 1990) has shown that approximately 20% of the on-road vehicles emit nearly 80% of the CO. Remote sensing methods take the ratio of CO in vehicle exhaust to the increment in carbon dioxide (CO_2) above unpolluted air. This ratio is proportional to the amount of CO emitted per quantity of fuel consumed. A pilot study by Lawson et al. (1990) in Southern California indicates that the high- and super-emitters cannot necessarily be identified by model year or by the time which has elapsed since their most recent inspection and maintenance.

While these studies are specific to CO, they call into question the modeling assumptions which affect all pollutant emissions rates estimated. For example, Hansen and Rosen (1990) report the only individual vehicle measurements of particulate emissions, and their results apply only to the ratio of light-absorbing carbon to CO_2. They found a factor of 250 between the highest and lowest ratio of light-absorbing carbon to CO_2 for 60 gasoline-fueled vehicles. They did not categorize vehicles by weight and age.

Continued use of the current "standardized" motor vehicle exhaust emissions models will not improve emissions estimates. Section 3 describes the limitations in these models in greater detail. One alternative to be considered is to derive empirical on-road estimates of particulate emissions using remote sensing. Stedman (1991) has modified the remote CO sensor which he has developed to measure the attenuation of light at wavelengths which are specific to CO and hydrocarbons. It is also possible to measure light extinction across a broad bandwidth which can be related to particulate matter emissions. Stedman's method includes freeze-frame video images of vehicle license plates. The ratio of visible light transmission to CO_2 can then be related to the grams of pollutant emitted per gallon of fuel consumed. With reasonable assumptions about vehicle mileage, this can relate emissions to VMT. In this way, an empirical model of pollutant emissions per VMT can be determined for different types of roadways, driving conditions, and times of day. With appropriate analysis of the types of vehicles tested, it might be possible to identify which are the major emitters of VOCs, CO, and PM_{10} and to focus control measures on these vehicles.

2.3 Spatial and Temporal Variations

Spatial and temporal variations in emissions are needed to evaluate different work schedules and land-use planning strategies for reducing air pollution concentrations. These variations can be partially addressed by the transportation demand models, but provision for them must be specifically programmed into those models. Temporal variations in emissions also result from meteorological conditions. For example, the evaporation rate of VOCs increases as temperatures rise, while CO emissions are higher upon start-up in cold weather than they are in hot weather. Provision needs to be made for the input of diurnal temperature variations into the calculation of emissions rates, and a flexible system of allocating emissions to locations is also required.

2.4 Speciation

Chemical speciation is important for volatile organic compounds (VOCs) which take place in ozone reactions and for PM_{10}. This speciation is needed both the verify emissions estimates against ambient data (using receptor modeling) and to estimate the effects of emissions on secondary pollutants such as ozone, sulfate, nitrate, and organic particles.

The most complex speciation is needed for VOCs. This speciation is needed for fuels which might be used in the future as well as those which are used today so that the effects of these fuels on ozone can be evaluated. The species need to be identified so that they can be efficiently combined into the groupings which are used in current air quality chemical modules.

The Auto/Oil testing data set provides a rich source of information which can serve as a starting point for this speciation. More tests are needed, however, to confirm that these dynamometer test data actually represent the hydrocarbon species found to be emitted from vehicles operated on the road.

3.0 EMISSIONS RATE SUB-MODEL

As described in the previous section, a number of distinct components are combined to yield the motor vehicle emissions modeling systems used in constructing current emissions inventories. Weaknesses in the components were described and potential improvements identified. In this section, we further describe limitations in the emissions rate sub-model and areas for improvement in future models. The SCAQS Tunnel Study and California's EMFAC provide the context with which these deficiencies are described; however, the criticisms also apply to EPA's MOBILE model.

3.1 Limitations of Current Models

As part of the review of the SCAQS Tunnel Study (Gertler et al., 1991), the study was examined to determine whether or not experimental differences might account for the discrepancies found with respect to the EMFAC7C emissions model. The experimental differences included: 1) biases in the chemical measurements; 2) inaccuracies in the tunnel flow measurements; 3) backflow at the tunnel exit; 4) correlations between tunnel flow and emissions; 5) calculational errors and uncertainties; 6) differences in vehicle operating conditions; 7) differences in vehicle distributions; and 8) representativeness of the samples taken. It was determined that none of these (or even all taken together) were sufficient to account for the observed differences. Furthermore, the impact of any experimental errors becomes irrelevant when one considers concentration ratios or emissions-rate ratios. These too, however, were found to differ by factors of close to 3 or more. The evaluation of the differences in the ratios of emitted species implied that the limitations in EMFAC and MOBILE owe less to deficiencies in the models than to limitations in the data base used to construct the emissions rate model input (Gertler et al., 1991).

Based on review of the models and their development and comparison with historical data, there are a number of groupings of questions about the input assumptions. These include:

- Representativeness of the volunteer fleets for estimating maintenance/deterioration;
- Representativeness of the volunteer fleets for estimating emitter level distributions;
- Speed correction factors (treatment of engine load).

Other questions such as the fraction of vehicles operating in a cold-start mode and impact of evaporative emissions can be posed; however, they cannot explain the differences in the ratios. For this reason, we believe the three groupings listed above to be at the heart of the model underpredictions in both the SCAQS Tunnel Study and other on-road applications.

3.2 Maintenance/Deterioration

In order to establish maintenance/deterioration rates of the vehicle distributions used in EMFAC and MOBILE, volunteer fleets were solicited. The response to the EMFAC mailing was on the order of 2 to 5% (Susnowitz, 1990). While this was checked and scaled based on motor vehicle records to ensure that the age and model distributions were appropriate (see paper by Carlock in CRC, 1990), there are questions as to whether high emitting vehicles, tampering, and poor maintenance were adequately represented. Could there have been any "filtering"? (That is, could owners who allowed testing have had generally better-maintained vehicles than those who declined?) In addition, what would happen if retesting were extended back beyond the 8-

year period used to construct the input data base - would the growth-rate assumptions used to transfer vehicles to higher-emitting categories remain valid? Considering the paucity of surveillance data for vehicles more than 10 years old, it is difficult to answer these questions.

The tampering factor in EMFAC7C may also be low. Cars that have been tampered with or "arguably tampered" with constitute 31% of the automobiles and light-duty trucks in the U.S.(EPA, 1989). The tampering factor is adjusted based on a comparison of the volunteer fleet data with inspection and maintenance (I/M) and surveillance data; however, this still may not be satisfactory since the average g/mi from the tampered-with vehicles in the these fleets may not be the same as (may be less than) the average g/mi from the tampered-with vehicles at large.

The impact of unregistered vehicles is unclear. For example, an estimated 6% of the vehicles in the Lynwood area of L.A. are not even registered (Lawson et al., 1990) and are presumably less likely to be properly maintained than the rest of the vehicles. Deterioration-factor estimates may also be too low, and there appears (Lawson et al., 1990) to be a large jump beyond 80-100 thousand km and/or for vehicles older than 25 years.

3.3 Emitter Level Categories

The input to EMFAC is divided into a series of categories by level of emissions (super to low) for each vehicle type. As with the vehicle maintenance/deterioration rates, the distribution of vehicles within emitter level categories is determined from the volunteer fleet. On-road remote-sensing CO data compared to CO distributions in volunteer test fleets suggest that the prevalence and emissions rates of the highest emitting vehicles are also underestimated. The remote sensing results of Bishop and Stedman (1990) Lawson et al. (1990) and Stephens and Cadle (1991) indicate a higher fraction of high CO emitters than previously believed, including even some vehicles emitting more CO than CO_2, and demonstrate the limitations in I&M programs in reducing emissions from this category. The results also point to a small fraction of each model year distribution (including the most recent vehicles) as falling into the highest emitting category. All of the remote sensing results indicate that less than 10% of the vehicles are responsible for 50% of the CO. Recent results for aerosol black carbon have also indicated a similar trend (Hansen and Rosen, 1990).

3.4 Speed Correction Factors

The speed correction factors used as the model input are derived from nine transient tests (not steady-speed tests) including the light-duty-vehicle FTP. The tests span a series of average speeds up to 65 mi/h. Running the nine cycles and scaling them to construct the speed correction curves may not accurately mimic real-world driving conditions. Inherent in this derivation of the speed correction curves is the assumption that averages in the skewed distributions representing the range of emissions at measured speeds can be validly combined to yield emissions factors for other (non-measured) speeds. On cycles other than the FTP, emissions are less well known since far fewer vehicles are tested on the other cycles. Actual emissions at a given speed depend on load (e.g., acceleration); hence, for example, the fluctuations about a given average speed - their amplitudes, time constants, and frequency of occurrence - will greatly affect the emissions accompanying that average speed. Real-world conditions may, in some cases, exceed the valid range of the test cycles; for example, real-world speeds often exceed 65 mi/h, and real-world accelerations commonly exceed the 3.6 mi/h-s maximum in the FTP cycle.

The importance of both accelerations and super-emitters may also be underestimated by the models. In a study by Lawson et al. (1990), it was observed that 10% of the vehicles produced 55% of the CO, while Groblicki (1990) has reported that a single power acceleration can produce more CO than is emitted in the balance of a trip. This raises doubts over the validity of the FTP for use in assessing the true impact of accelerations on tail-pipe emissions and it is apparent that both the effect of accelerations (and hence load) and impact of super-emitters are underestimated factors in producing emissions. The validity of predicting emissions on the basis of a speed correction curve that takes no account of the amount of acceleration in the various tests from which the curve is constructed, and further may underestimate the impact of super-emitters, is questionable at best.

4.0 RECOMMENDATIONS AND CONCLUSIONS

4.1 Recommendations for the Year 2000

The primary step in developing a model for the Year 2000 is to recognize and address the deficiencies in the current methodology. As mentioned previously, the approach taken in this evaluation is biased towards addressing the emissions rate sub-model. Other parts of the mobile source emissions model system will also need to be addressed. Recommendations for a revised model include:

- Developing more efficient and flexible hardware and software platforms for the system and documenting the combination of travel demand, emissions rate, temporal distribution, and speciation modules that are developed.

- Developing a user-friendly package that allows the community to evaluate multiple control scenarios.

- Allowing the user to accurately estimate the relative amounts emitted by different vehicle types such as diesel, super-high emitters, and new-model passenger cars.

- Providing accurate estimates of emissions factors for calculating base emissions levels.

- Specifying model precision and accuracy for evaluating potential control strategies.

- Improving spatial, temporal, and chemical resolutions to target the locations, times, and reactivities of emissions reductions.

- Adding accurate organic speciation (rather than just HC emissions) for the evaluation of reactivities of emissions from current fuel mixture and alternate formulations of transportation fuels and their delivery systems. This is particularly critical for evaluating ozone control strategies.

- Adding PM_{10} in addition to CO, HC (or speciated organics), and NO_x to the model output since many areas are or will be in non-attainment with respect to that category.

- Upgrading traffic demand models to provide VMT for defined vehicle classes along each roadway segment as a function of time. This is important since the distribution of heavy-duty diesels and light-duty passenger cars, and the speeds at which they travel, are much different for: 1) expressways; 2) freeways; 3) arterials; 4) arterials-2; 5) collectors; and 6) centroid connectors.

- Deriving empirical on-road estimates of emissions using remote sensing rather than extrapolating from dynamometer tests. Stedman (1991) has modified the remote CO sensor which he has developed to measure the attenuation of light at wavelengths which are specific to CO and hydrocarbons. Measuring light extinction across a broad bandwidth which can be related to particulate matter emissions is also possible.

4.2 Conceptual Model for Motor Vehicle Emissions

The current combination of travel demand, emissions rate, temporal distribution, and speciation modules are undocumented, untraceable, incompatible, and inflexible. This makes these models difficult to update and does not allow information to be traced to its sources.

Given today's computational capabilities and information resources, the standard definition of an air quality emissions inventory as a spatially and temporally averaged listing of presumed emissions is antiquated. The prevailing concept in scientific circles is that of an Emissions Modeling System (EMS). An EMS is capable of accessing activity data bases from a multitude of information-gathering agencies. The EMS then combines this information with meteorological data and validated emissions/activity relationships to provide emissions rates for any selection of location, time, or sources. Figure 4-1 shows a block diagram of such an EMS.

An EMS has the following attributes: 1) it is based on documented scientific and engineering principles; 2) it is composed of special-purpose modules which can be updated with new information and new science when they are available; 3) its activity levels and emissions/activity relationships are specific to the area being modeled; 4) it contains error propagation algorithms to provide precision estimates on outputs; 5) it uses independent activity data bases and emissions/activity relationships of equivalent quality to estimate accuracy; 6) it adjusts the emissions/activity relationship in response to environmental variables, especially meteorology; 7) it allows the addition, subtraction, or modification of emissions for specific days; 8) it retains traceability of all information to allow quality auditing; and 9) it provides output displays, statistics, and data bases which can be used for modeling, data analysis, and quality assurance.

Unfortunately, there is no EMS used or even currently available which attains these attributes, though many who have developed emissions inventory systems claim otherwise. Attempts have been made to improve the current state of the art with the creation of the Flexible Response Emissions Data System (FREDS) (Lebowitz et al., 1987) for the National Acid Precipitation Assessment Program (NAPAP) and the Emissions Preprocessor System (EPS) for the Urban Airshed Model (SAI, 1990). These are no more than data management systems and contain nothing pertaining to travel demand or emissions rates. Though these are improvements over currently used methods, mostly with respect to data handling, they do not attain the attributes specified above nor are they easily adaptable to emissions in other areas.

An EMS which is intended to possess these attributes is currently under development as part of the San Joaquin Valley Air Quality Study and Atmospheric Utility Signatures, Predictions and EXperiments (SJVAQS/AUSPEX) in California. While this development will not be completed until sometime in 1992, the conceptual structures being developed are directly applicable to the issues addressed in this document.

An ideal EMS consists of several relational data bases which contain different types of information. At the base level are activity data from which total emissions are derived. These data are obtained from a number of sources, and wherever possible there will be different activity data for the same sources and emissions species. For example, PM_{10} from construction and demolition might be independently calculated from construction permits and from U.S. Census TIGER/Line land-use designations and population growth projections. Differences between activity estimates can be used to quantify the uncertainty of emissions rates.

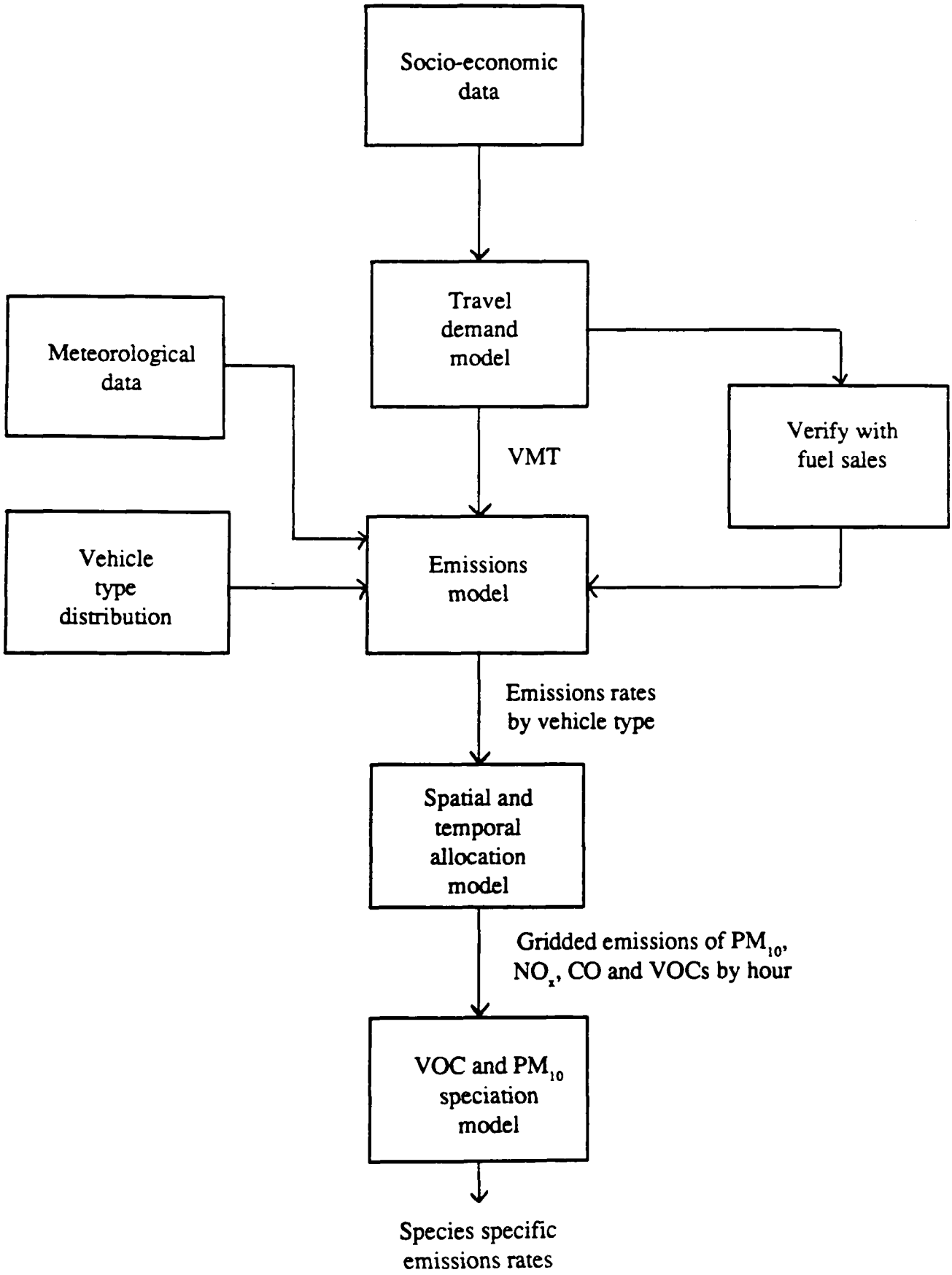
Socio-economic data
Travel demand model
Meteorological data
Verify with fuel sales
VMT
Vehicle type distribution
Emissions model
Emissions rates by vehicle type
Spatial and temporal allocation model
Gridded emissions of PM_{10}, NO_x, CO and VOCs by hour
VOC and PM_{10} speciation model
Species specific emissions rates

Figure 4-1

Upon these activity data are imposed emissions/activity relationships (commonly termed "emissions factors") which may require meteorological inputs such as temperature, relative humidity, or wind speed. These relationships are easily replaceable and include the ability to propagate the precisions specified for the input data. The emissions/activity relationships are specific for different source sub-types. As an example, certain roads may have greater or lesser proportions of diesel truck traffic, older and newer vehicles, and vehicles which were recently started and ones which are fully warmed up. In the idealized EMS, each road segment is assigned a classification for a specific distribution of vehicles, and a separate emissions/activity relationship is determined for each classification.

An EMS is constructed using commercially available Relational Data Base Management Systems (RDBMS) and Geographical Information Systems (GIS). Hardware adequate for a typical urban area (even one the size of the South Coast Air Basin) can consist of a desktop workstation with a high-resolution color monitor, high capacity (>500 Mbyte) disk drives, optical storage media, document scanner (for maps), and color plotter/printers. The RDBMS contains the needed data and performs mathematical operations, while the GIS accesses geographical data bases, allocates spatial information to grid squares, and drives the display hardware.

An EMS of this type is being constructed as part of SJVAQS/AUSPEX for central California. This system might serve as a platform for further motor vehicle emissions model development.

4.3 Availability of Data

Currently available "useful" data are limited. As described previously, on-road and ambient data imply that the current methodology is inadequate and continued use of the current "standardized" motor vehicle exhaust emissions models will not improve emissions estimates. A number of large emissions rate data bases using remote sensing methods have, however, become available (e.g., Bishop and Stedman, 1990; Lawson et al., 1990; Hansen and Rosen, 1990; Stedman, 1989; Stephens and Cadle, 1991). These could be used as a base for developing empirical on-road estimates of emissions.

The Auto/Oil testing data set provides a source of information which can serve as a starting point for organic speciation. More tests are needed, however, to confirm that these dynamometer test data actually represent the hydrocarbon species found to be emitted from vehicles operated on the road.

As detailed in Section 4.2, the approach of developing an EMS with the stated attributes may be chosen. If this is the case, the conceptual structures being developed as part of SJVAQS/AUSPEX can be used.

4.4 Evaluation and Reconciliation

In order to evaluate the emissions rate model, a systematic approach must be taken. Step 1 is an operational evaluation of the model. This would involve testing a vehicle fleet that is specified by, and under the control of, the experimenter. The SCAQS Tunnel Study was not such an experiment. It was not originally designed to evaluate automotive emissions models, but merely to provide input for calculation of the SCAQS emissions inventory. In an experiment with a test fleet, the model would be applied to calculate absolute emissions factors and stated

uncertainties therein and compare them with observations of known accuracy, precision, and validity. This would permit reformulation of the model inputs, given the knowledge of the distribution of modes, speeds, grades, and other operating conditions, to predict accurately the observed on-road results.

Step 2 would involve testing of the adjusted model in a second experiment, in a real-world setting, where it can be validated against actual driving situations. In this experiment, conducted under passive conditions, driver consent is not necessary and remote-sensing would be required to tell where model inputs may be off and would yield information critical to determining actual instantaneous vehicle emissions rates. It would also be necessary to verify the instantaneous results obtained by remote sensing against results obtained over a longer time period by performing either multiple remote sensing measurements or on-board measurements on a few vehicles.

A corollary to this approach would be to include uncertainties in all model outputs. If, as the tunnel experiment and other data imply, automotive emissions are a greater proportion of the urban hydrocarbon emissions than previously believed, then even relatively small uncertainties in the measurements (10-20%) can have a major impact on the development of abatement strategies. On the other hand, if the contribution of vehicle emissions is small compared with the total, then large uncertainties will not be as critical. Without knowledge of the uncertainty in model output data, it is difficult even to know which regime one is dealing with and therefore to know how good the model needs to be.

4.5 Estimated Costs of Development and Evaluation

If the approach outlined of using input derived from empirical on-road estimates of emissions using remote sensing rather than extrapolating from dynamometer tests is used, then development costs will be minimal. The physical hardware for obtaining the data currently exists. The main cost would be in obtaining remote sensing data in the field; however, this expense would be offset by savings from not performing dynamometer tests.

The expense of developing improved models rather than using improved inputs is difficult to quantify. Based on the SJVAQS/AUSPEX effort, we estimate a cost of $2M excluding in-kind services.

We are currently in the process of planning a model validation study for the Southern Oxidant Study that parallels that outlined in Step 2, above. The total cost (including in-kind services) will be approximately $1.5M. Costs for the total evaluation and reconciliation effort would be on the order of two times that level. Periodic re-evaluations should also be budgeted for.

4.6 Summary

Mobile source emissions estimates used throughout the U.S. for developing air pollution abatement strategies may be off by as much as a factor of two or more for both hydrocarbons (HC) and carbon monoxide (CO). Since motor vehicles are the dominant source of these species in many non-attainment areas, such large errors make determination of appropriate abatement strategies difficult and prone to error. In addition, current mobile source emission factor models

are not user friendly nor are they designed to evaluate the impact of reformulated fuels, new technologies, and new control strategies.

The perspective taken in this document to address these deficiencies is based on the experiences of the authors in evaluating (Pierson, 1989; Pierson et al., 1990; Gertler et al., 1991; Gertler and Pierson, 1991) and applying (Chow et al., 1991; Watson et al., 1990) motor vehicle emissions models in non-attainment areas. This perspective is somewhat limited since the primary emphasis has been on the emissions rate sub-model of the modeling system used in constructing the mobile source contribution to the inventory.

Weaknesses in the components used to construct motor vehicle emissions models were described and potential improvements identified. In particular, limitations in the emissions rate sub-model were addressed and areas for improvement in future models were noted. Experimental studies and quality assurance activities needed to provide model input data and evaluate model results were also specified.

By concentrating on improving model inputs rather than developing new models, costs can be minimized. Periodic on-road validation tests would, however, be required to verify assumptions and data acquisition methods.

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APPENDIX C

CONCEPTUAL DESIGN FOR A NEW HIGHWAY VEHICLE EMISSION ESTIMATION METHOD

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SECTION 1

INTRODUCTION AND SUMMARY

Our conceptual design for highway vehicle emissions focuses on improving the interaction between what have been termed the emission factor modeling and transportation modeling portions of the emissions estimation process. It is our observation from the workshops and from other related meetings that while transportation models are not perfectly designed for use in producing air pollutant emission estimates, the four step travel forecasting process is the best tool for performing urban scale analyses and meeting the needs for highway vehicle activity level information. We see no need for a complete redesign of this process. As such, we recommend that new modules be added to the emission and transportation portions of the overall emission estimation process and that common data sources useful to both parts be identified and exploited to more fully integrate these two processes.

Our specific recommendations are: (1) that three new models be developed within the travel forecasting process to estimate the percentage of travel occurring in various operating modes, to identify the cold starts and hot soaks of vehicle trips as a function of the temporal spacing of these trips, and to quantify trip reduction effects of transportation control measures; (2) that a macroscale model of vehicle miles traveled (VMT) and vehicle trips be developed for areas outside the urban cordon area; (3) that there be more collection and analysis of modal emission data and that it be incorporated into the emission factor model; (4) that EPA take advantage of opportunities for collecting data at inspection stations; and (5) that onboard computer recordkeeping be used in conjunction with auto use surveys.

This short report is organized as follows. We begin with a short summary of the history of motor vehicle emission factor models, which is followed by an overview of the four step travel forecasting process. Our proposed conceptual design for a new highway vehicle emission estimation procedure follows the summary information.

SECTION 2

BACKGROUND

HISTORY OF MOTOR VEHICLE EMISSION FACTOR MODELS

Programs to estimate mobile source emissions and to provide emission factors for use by State and local agencies have been ongoing since 1968. Standard EPA publication of such emission factors began in 1975 in AP-42, which provided emission factors for 1972 and earlier model year vehicles. At that time, mobile source emission factors were provided in tables, and if correction factors had to be applied by a user to develop city-specific emission estimates, calculations were performed by hand. If an analysis of more than moderate complexity was needed, the calculations quickly became cumbersome. Thus, some sophisticated users of the data started to develop their own computer routines to perform some of the calculations that were possible using AP-42 data. EPA's Office of Air Quality Planning and Standards (OAQPS) developed a computer program with the acronym MVEEP (Motor Vehicle Emissions Estimation Program), which could be used to estimate mobile source emissions of light-duty vehicles for the calendar years 1970 through 2000. A program with similar capabilities was developed by New York City and was titled BIG AP-42.

To meet the demand for computerized mobile source emission factors, EPA's Office of Transportation and Land Use Policy hired a contractor to provide a computerized mobile source emission factor model. When this model was completed, it was coined "MOBILE1". This computer program and an accompanying document were issued in 1978. SIP analyses for CO, ozone, and NO_2 that have been prepared since the release of MOBILE1 have had to incorporate this program or its successors into any mobile source emissions analysis. Because States have submitted SIPs and revisions to those SIPs since 1978, the MOBILE model user community has evolved into a fairly sophisticated group.

MOBILE1 and MOBILE2 both contained options to produce California emission factors, but with CARB producing its own emission factor model (EMFAC) and the confusion that ensued from having different emission factors for this State produced by the two models, EPA stopped including the California emission factor option in its model. MOBILE4 provides high and low altitude 49-State emission factors.

While the current versions of the motor vehicle emission factor models that have been produced by EPA and CARB allow users to model the effect of many more variables now than was possible 10 years ago, the level of uncertainty associated with the resulting emission factors is great, especially under the extreme conditions that are often characteristic of air pollution episodes. About two years ago, the discovery of excess motor

vehicle evaporative and running loss organic emissions under high temperature ozone season conditions made it apparent that the emission factor models of the time underestimated organic emissions. MOBILE4 incorporated these running loss emissions as well as excess evaporative emissions, but because of the limited number of vehicles tested, commitments to release MOBILE4 at an early date, and technical/policy concerns at EPA about how to interpret the data, there remains considerable uncertainty in the organic emission factors. Recent attempts to compare ambient CO, HC, and NO_x measurements with emission factors have also shown that the motor vehicle emission factor models continue to underpredict CO and organic emissions. Thus, the need exists to more accurately determine actual emission rates and correctly simulate them in models.

Figure 1. provides our assessment of the information flow in the "current form" motor vehicle emission factor model. Interactions with transportation data are noted on Table 1.

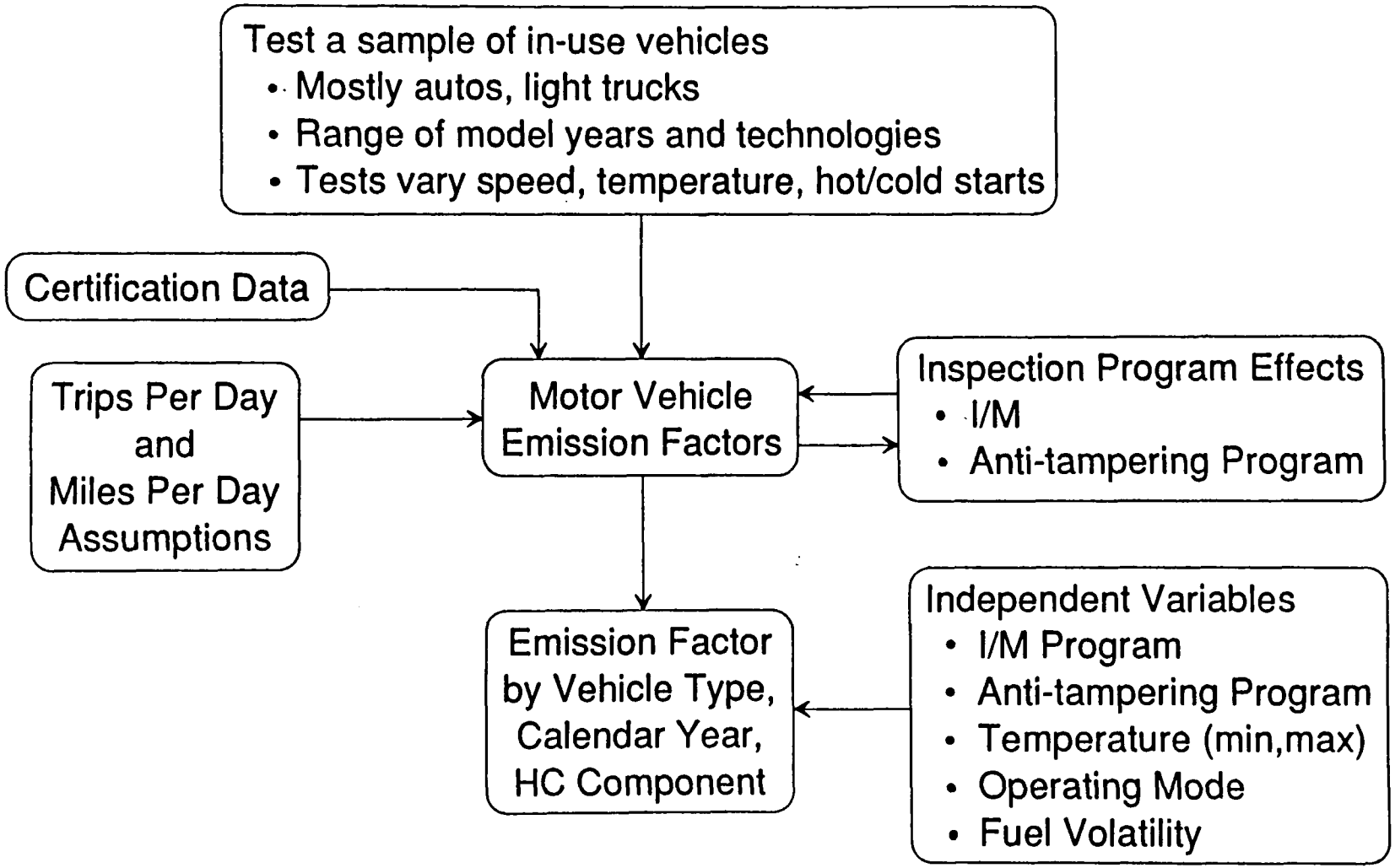

Figure 1. Motor Vehicle Emission Factor Modeling

TABLE 1. INFORMATION INTERFACE WITH TRANSPORTATION MODELS

1. Speeds vehicles are traveling
   - normally determined by roadway functional class
2. Vehicle miles traveled (VMT) by vehicle type
3. Yearly mileage driven by vehicle age
4. Operating Mode Fractions (cold and hot starts)
5. Travel - VMT/trips (by vehicle type)

Local area data in addition to the above

1. Low or high altitude location
2. Fuel volatility
3. Ambient temperatures
4. Registration distribution by age

As an introduction to the proposals for improving aspects of the travel demand forecasting process to better estimate mobile source emissions, it is useful to briefly summarize the current state-of-the-practice in urban travel demand forecasting, indicating where current practice may introduce errors into the emissions estimation process. The following section provides a summary of this process.

TRAVEL DEMAND FORECASTING PROCESS

The current travel demand forecasting process as practiced by most state DOTs and Metropolitan Planning Organizations (MPOs) consists of the following five major steps as shown in Figure 2:

1. land use/demographic forecasting
2. trip generation
3. trip distribution
4. mode choice
5. trip assignment

This process is applied to the geographic area within each urban area referred to as the transportation planning "cordon area". This cordon area is typically defined to include the observed "commuter shed" around the central city of an urban area. The cordon area will change over time as the urban area grows and is typically adjusted once every ten or so years based upon information from the decennial census. The expansion of the cordon area is typically a major technical effort as the travel forecasting models must be adjusted or recalibrated to include the travel patterns of the newer, expanded suburbs and exurbs of the urban area. The cordon area for which travel forecasts are made may or may not coincide with the geographic area defined as the urban airshed for an urban area.

Each of the steps in the travel forecasting process will be briefly summarized in the following subsections.

Land Use/Demographic Forecasting

Person travel and goods movement is a derivative of the spatial separation of human activities within urban areas. In order to forecast the amount and location temporal distribution of travel, forecasts must first be made of the spatial distribution and characteristics of land use and urban populations. These forecasts are typically independent of the characteristics of the urban transportation systems, but are inherently dependent upon them. These land use and demographic forecasts are also typically made by staff independent of the staff performing the travel forecasts for each urban area.

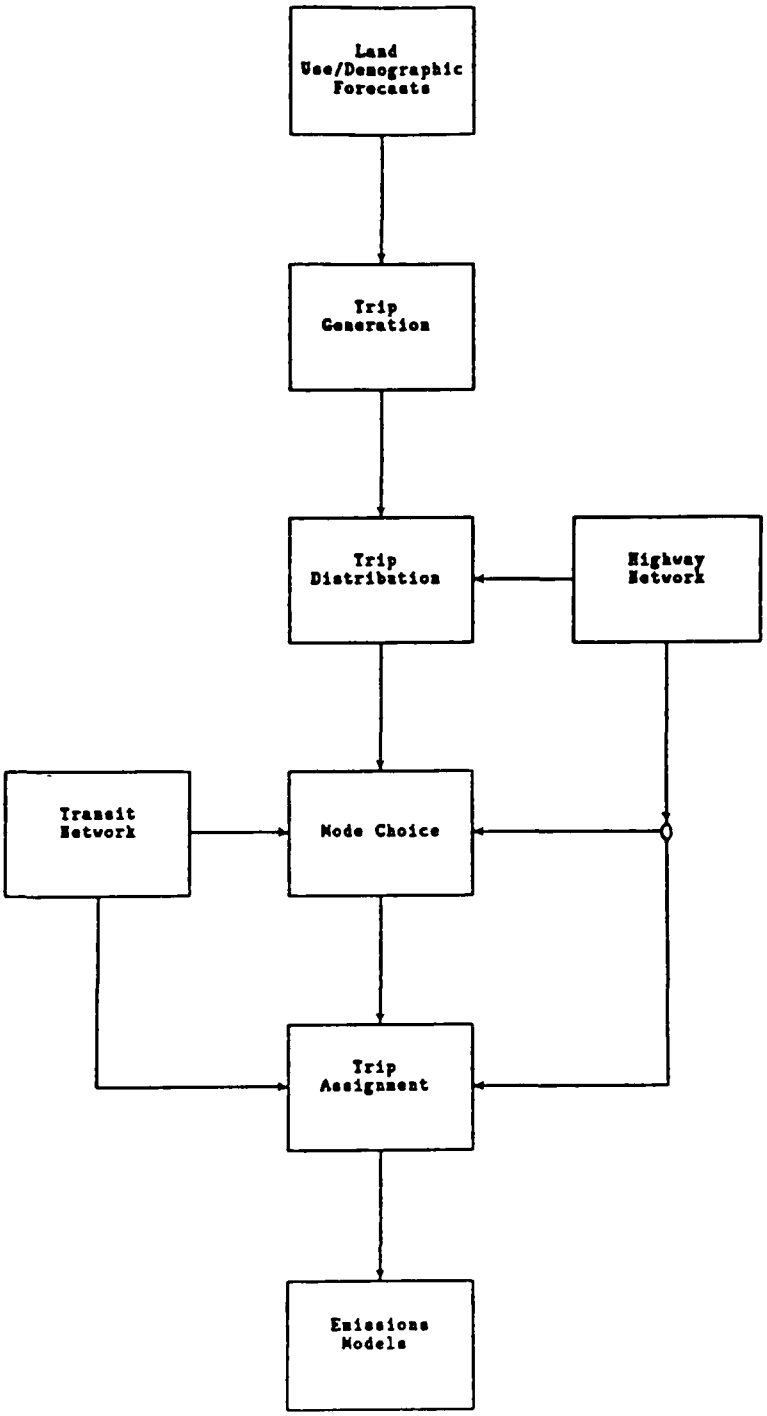

Figure 2. Conventional Urban Travel Forecasting Process

Regional and/or county level forecasts are typically made for population, households, and employment by type (e.g.: retail, other service, manufacturing, etc.). These forecasts must then be geographically disaggregated to smaller geographic units, called traffic analysis zones (TAZs), which form the geographic basis for the travel forecasting process. Urban areas typically are divided into approximately 400 to 600 zones per million population. Most agencies develop TAZ level land use/demographic forecasts in two steps: 1) from region to district (or jurisdiction) and 2) from district (or jurisdiction) to TAZ. Generally, district level allocation methods do not produce all required inputs (e.g. household car ownership, household income, household size distribution, etc.) for the travel forecasting process. Hence a postprocessing procedure is commonly applied.

The methods used to prepare TAZ forecasts are very diverse and their use in an urban area depends upon local circumstances. These methods range from simple analytical methods and Delphi techniques to complex mathematical models. Because inputs provided by local jurisdictions are crucial to the accuracy of the TAZ allocation process, these local jurisdictions are often responsible for the allocation task.

The accuracy of the travel forecasts is in turn a function of the accuracy of the land use/demographic forecasts. These demographic forecasts in rapidly growing urban areas are more likely to be erroneous than those for more slowly growing urban areas. Hindsight shows that the errors in earlier travel forecasts are in large part due to the errors in the forecasts of the magnitude and geographic distribution of population and employment, as well as missing the advent of major demographic changes such as the tremendous increase in two-worker households over the past two decades.

Trip Generation

Trip generation refers to the set of models in the four step travel forecasting process which estimate the number and purpose of the person trips generated by the residents and employees of the urban area. Most trip generation models estimate the number of trip productions (the home end of each trip) and trip attractions (the non-home end of each trip) by trip purpose (typically home-based work, home-based other, non home-based). The typical variables used to forecast trip productions and attractions are the number of households per TAZ, persons per household, household income and/or vehicle ownership and employment by TAZ stratified by type of employment.

As with all models in the travel forecasting process, the trip generation models are typically calibrated with travel survey data collected locally in each urban area relating the amount of trip making to the variables listed above.

It is assumed that trip generation rates are stable over the time period of the forecasts and that the trip production and attraction rate relationships to the chosen independent variables reflect stable relationships among the non-modeled contributory variables.

Trip Distribution

Trip distribution is the model which allocates each of the trip productions to each of the trip attractions, creating the geographic linkages between the production and attraction ends of each trip. The most widely used trip distribution model is the "gravity model" which forecasts that the probability of a trip being produced in TAZ x and attracted to TAZ y is directly proportional to the fraction of the regional trip attractions which lie in TAZ y and inversely proportional to the travel impedance required to travel between TAZs x and y. The model is calibrated and applied to each trip purpose separately. The model is typically not sensitive to any socio-economic characteristics of the trip makers (e.g. household income and employment classification). The model typically uses estimated highway travel time as the measure of highway impedance between traffic zones. The model is calibrated to each specific urban area by estimating a set of "friction factors" which represent the effects of travel impedance separation between TAZs on the likelihood of travel between TAZs.

The gravity model, if not stratified by socio-economic characteristics, can incorrectly estimate the specific linkages for work trips between households of a particular socio-economic status and employment locations of a different status. The gravity model can also wrongly estimate trip distribution patterns for urban areas with well developed and utilized transit systems unless the model is calibrated to a multi-modal measure of travel impedance which includes transit accessibility measures.

Mode Choice

Mode choice models are common in most of the larger urban areas with populations over one million. The current state-of-the-practice mode choice model is the multinomial logit model, which relates the share of each travel mode (e.g. drive alone, transit, carpool) to variables which represent the socio-economic characteristics of the trip-maker, the characteristics of the ends of the trip (e.g. density of development) and the travel time and cost of each mode for each TAZ-to-TAZ movement. The model is calibrated to each urban area by estimating a set of coefficients which reflect the observed "importance" of each variable to the share of trip-makers, by trip purpose, who choose each mode.

Mode choice models can typically do a good job of replicating region-wide mode shares. They are less accurate in

estimating mode shares for specific travel corridors or subareas within urban areas. They also do a better job of estimating transit shares to the downtown area than within suburban jurisdictions. Regional mode choice models typically do not include variables that allow them to accurately estimate many transportation control measures (TCMs), particularly those that are employer based.

Trip Assignment

Trip assignment is the process of allocating the TAZ-to-TAZ trips by mode to the respective networks representing the highway and transit systems in the urban area. The highway traffic assignment process allocates auto (and in some urban areas, truck) trips to the highway network based upon the minimum impedance paths through the network from each TAZ to each TAZ. Capacity restraint is typically applied during the assignment process to "spread" the vehicle trips over a series of paths as a function of the estimated congestion on each link forming each path. Most urban areas perform assignments of average daily weekday traffic resulting in estimated 24 hour traffic volumes by facility. Estimates of traffic by time period are usually made by applying diurnal factors derived either from traffic counts or from travel surveys.

General Improvements to the Travel Forecasting Process

There are several improvements to the travel forecasting process which, though not specifically targeted at improving emissions estimates, would improve estimates of urban travel and hence the accuracy of emissions estimates. While it is not advocated that EPA take the lead in promoting this research, these research topics are brought to EPA's attention so that an EPA awareness develops of what we believe are additional travel forecasting research needs. These are listed below. Each research need is identified as achievable in the near term (1-3 years) or the long term (4-10 years):

- Develop/refine travel forecasting procedures that explicitly account for the interrelationship between land-use development patterns and transportation infrastructure (highway and transit) (long term)

- More fully integrate the components of the conventional 4-step travel forecasting process to form fully policy sensitive travel forecasting methods; this probably requires replacing one or more of the conventional steps with new methods (near and long term)

- Develop models to better represent vehicle usage for linked trips and non-work travel (near and long term)

- Update and expand information on the diurnal distribution of vehicle trips (near term)

- Develop models to estimate heavy truck trip origin-destination patterns within urban areas and truck volumes by highway facility (near and long term)

- Improve traffic assignment procedures to be able to represent the impact of IVHS strategies on traffic flow (near and long term)

- Integrate transit park-and-ride vehicle trip estimates into emissions calculations (near term)

- Integrate transit bus trips/VMT into emissions calculations (near term)

- Incorporate GIS software in order to facilitate the storage and transfer of travel forecast data into the emissions/AQ models (near term)

SECTION 3

CONCEPTUAL DESIGN

Before developing the conceptual design, we first separated the needs that should be addressed by this design and have sorted them into primary and secondary needs.

Primary Needs

- must capture appropriate measures of vehicle activity (VMT, number of trips, speed, time of travel)
- variations in emissions by fuel type and vehicle type
- variations in emissions by operating mode
- criteria air pollutant and greenhouse gas emissions
- time of day variations
- spatial variations, including the ability to place emissions into a square grid network
- ability to perform forecasts
  [Estimating total daily or yearly emissions for a geographic area is more important than spatial or temporal allocations]

Secondary Needs

- reactivity of organics varies by exhaust, evaporative, running loss so it is helpful to tie these to the activities that produce them
- ability to provide county level emission estimates for the entire country
- fuel consumption estimates to help in tracking CO_2 emissions

IMPROVEMENTS TO EMISSION FACTOR MODELING

Our primary recommendation for improving motor vehicle emission estimates is to begin collecting and analyzing emissions data by mode. The objective is to be able to isolate exhaust emissions by the mode of operation, namely acceleration, deceleration, cruise, and idle. At the same time, a new module will have to be developed on the transportation side that allows one to pinpoint time in mode and identify profiles of trip-making. (This is described in more detail later.) Then, the above two steps are used together to develop daily emission profiles. There are a number of options that might be pursued for developing these profiles. Our initial thought is that daily profiles for the different emission components could be developed and would look similar to those shown in Figure 3. There are any number of ways that the data could be stratified when constructing these emission profiles. The objective is to have the smallest number of profiles possible to be able to accurately cover the variety of trip-making that occurs in an area. The illustrative profiles shown in Figure 3 are for a home-based work trip. At a minimum, there would be profiles for other HC

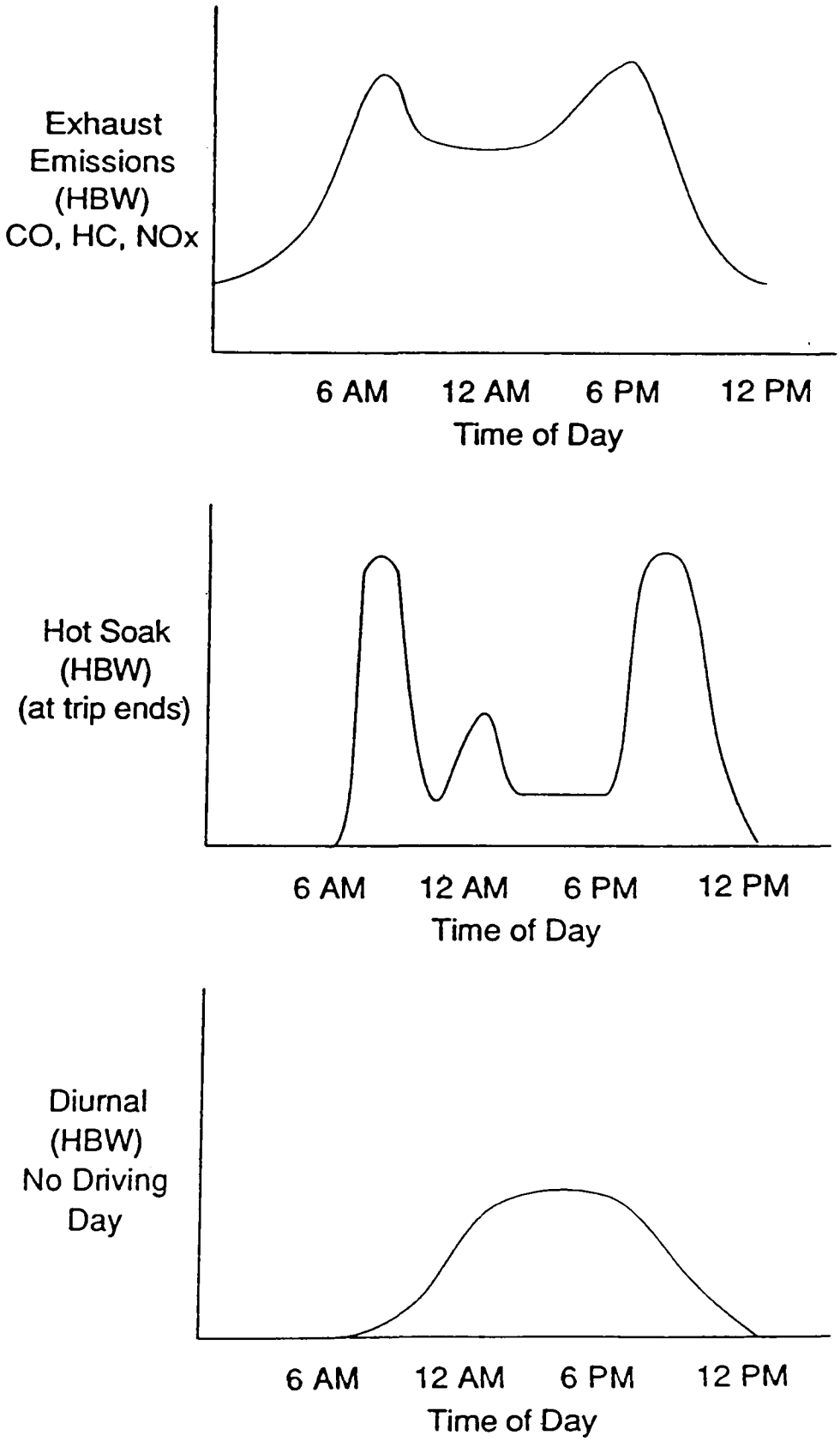

Figure 3. Example Daily Emission Profile

emission components, including other diurnals (x trips, y trips, multi-day), running loss, and resting loss. Presumably, there would be a variety of home-based work trip profiles to represent the variety of trip-making patterns within the urban area. Emission profiles could either be adjusted to represent the ambient conditions on an episode day, or could be seasonal.

The results of the above three steps could then be used to develop emission estimates in an integrated emissions/transportation model. Emissions profiles could be constructed endogenously, but we see value in being able to examine the profiles as an intermediate step in the process.

The other important area of motor vehicle emissions control is determining the percentage of vehicles emitting in the super, high/very high, and normal modes. Then, designing inspection, onboard diagnostic (OBD), and recall programs to catch and repair the highest emitters is important for future emission control success. For the most part, there are technological solutions to the "high emitter" problem. Catching 90 percent or more of the high emitters and repairing them to normal omitting levels can be achieved by the "best inspection and maintenance (I/M)" program. This performance requires a significant financial commitment to the new equipment and the attendant bureaucracy needed to track I/M, OBD, and recall efforts.

Our concern in designing emission estimation methods is not with solving these problems, but in considering their effect on emissions. Sampling for performing in-use emission tests, therefore, needs to be designed to effectively capture emission rates, the fraction of vehicles and their travel in each of the emitting categories (normal, high, very high, super), and as much information as possible about the reasons for failures when they occur. This type of data collection makes it possible to more accurately estimate base year emissions, and at the same time, estimate the effect of future control regimes on future year emissions.

Modal data will be more difficult to collect than Bag 1, 2, and 3 samples, but with improving computer technology, this sampling may prove less difficult than it has been in the past. Statistical techniques will have to be used to determine the number of vehicles that need to be sampled and the frequency of testing. While there may be some penetration into the vehicle fleet of alternative technologies and fuels in the next 10 years, current evidence points toward reformulated gasoline and advanced catalysts with fuel injected engines being the vehicle technology of the future. If this is the case, then, at least in theory, there would not be significant differences in emission characteristics within a vehicle class. Emission differences would then more likely be related to emission control component failures than to differences in control technologies. (This is probably already the case today with the TECH IV group as defined in MOBILE 4.) This may also reduce the need to characterize the

emissions from each model year's vehicles -- similar model years can be grouped.

It is clear from the current research on vehicle emissions that there are still some major unresolved issues. It has been known for some time that the Federal Test Procedure (FTP) is not representative of the driving conditions that are likely to lead to air quality standard violations. Whether the FTP continues to be cycle used for certifying vehicles, there needs to be an alternative "in-use" cycle that better characterizes actual driving. This cycle needs to include the ability to simulate "real accelerations," and perhaps it needs to be continually revised to account for changes in driving patterns.

On the other hand, whatever cycle is developed to simulate "in-use" emissions should be widely applicable. The assumption is that driving patterns do not vary much among cities. There may be special cases, such as Manhattan, that are not well served by the new cycle, but these will be few, and the New York City cycle already offers a profile of the driving patterns in that metropolitan area. It is only important that driving with each mode - acceleration, deceleration, cruise, and idle - be consistent from area to area, however, and that the cycle capture the full range of actual driving practices across various roadway types.

Even with alternative fuels, it is expected that manufacturers will design vehicles to certify to the applicable standards, so the variation in exhaust emissions among fuels may not be great. Separate evaporative HC emission profiles would have to be developed for alternative fuels if they achieve significant market penetration. If alternative fuels are primarily used in fleet vehicles, the different driving patterns of that type of vehicle will have to be considered.

Soon, there will be onboard diagnostic equipment on all new cars, and that, coupled with a trend toward (and perhaps an EPA requirement for) centralized I/M programs, presents a tremendous new opportunity for compiling historical data on yearly mileage for each car and light truck (and perhaps each heavy-duty gas truck), survival rates, and emissions-related performance. If transient testing is included in I/M programs, I/M test results should more closely approximate those of the FTP and can provide another useful data set on per vehicle emissions.

Increased sophistication of onboard computers also provides opportunities to coordinate auto use survey material for transportation planning with records of emission control system performance. Equipping the cars of households which are keeping travel diaries with diagnostic equipment that can keep track of throttle position, speed, etc. also provides significant opportunities for "cross fertilization" of data between transportation and environmental needs.

Motor vehicle emission factor models need to be configured to provide different outputs in order to serve different purposes. Having modal data available makes it possible to provide emission estimates for specific roadways or sets of roadways that are more likely to match with experimental data (and therefore, more useful for validation). MOBILE4 really provides data in a form most useful for performing regulatory analyses. It is not designed for grid-based model inputs either. In short, we are recommending that the data in the model be used in different ways to suit different needs. This means at least three different MOBILE4 output forms are needed; namely, (1) model, (2) grid-based episode day, and (3) regulatory analysis compatible.

IMPROVEMENTS TO THE TRAVEL FORECASTING PROCESS FOR BETTER EMISSIONS ESTIMATION

In order to better estimate vehicular emissions in the future, the travel forecasting process must provide different information about the traffic stream than has been provided in the past. This information will correspond to the input data requirements of the proposed new emission factor models described in an earlier section. Three new models within the travel forecasting process will be required to produce the information and sensitivities needed for improved emissions estimates. These models are:

- model to estimate the percentage of vehicle travel occurring in various operating modes
- model to estimate the cold starts and hot soaks of vehicle trips as a function of the temporal spacing of these trips
- model to estimate the trip reduction impacts of Transportation Control Measures (TCMs)

Each of these models will be discussed in detail below and their place in the travel forecasting process is illustrated in Figure 4.

Vehicle Mode Model

The purpose of this model is to provide percentage estimates of daily VMT that are expended in each of the four vehicle operating modes which are determinants of emissions:

- acceleration
- deceleration

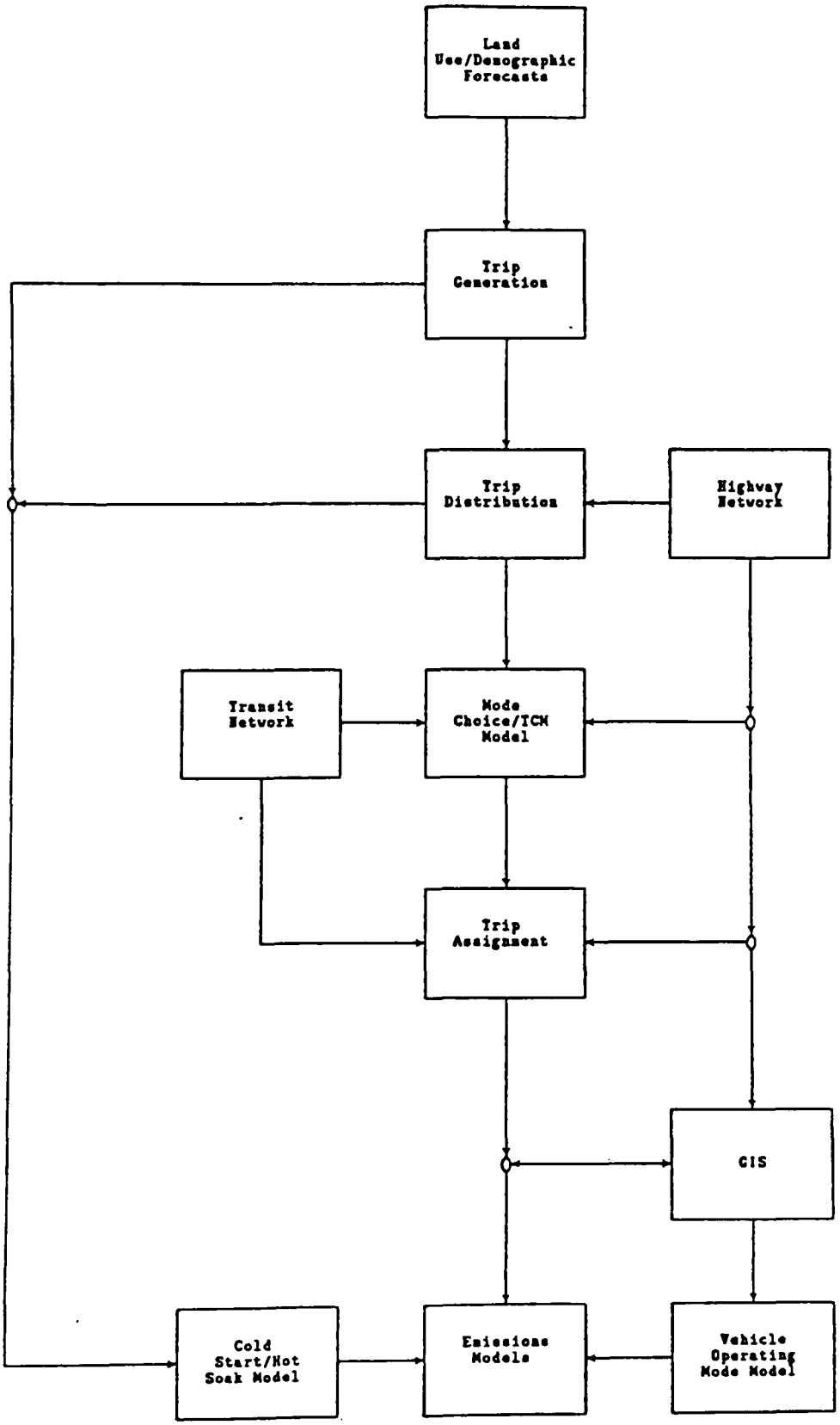

Figure 4. Revised Travel Forecasting Processes to Better Estimate Mobile Source Emissions

- cruise
- idling

It is proposed that the model estimate the percent of each vehicle trip spent in each operating mode as a function of the types of facilities (e.g. freeway, arterial) over which each vehicle trip is made, the volume/capacity (V/C) ratio of the facility, the time of day (peak and off-peak), and perhaps information about the traffic control device density on arterials (e.g. x traffic signals/mi.).

The current traffic assignment models can already report the percent of VMT that occurs on each facility type and in each V/C ratio range. These assignments typically reflect 24 hour average weekday traffic volume estimates. Traffic signal density by roadway link or by area type is a variable that can be maintained in the highway network data files, but would need to be added to those files for most urban areas.

The model would be calibrated based upon new data that need to be collected relating vehicle operating mode to the variables cited above. These data can be obtained by developing a sample of instrumented vehicle trips made in several urban areas over a range of facility types, traffic conditions, and times of day. The data could then potentially be reduced to a cross-classification model with the structure shown in Table 2.

The stratification of the variables would depend, of course, upon an analysis of the data collected. Each cell value would have both a mean and standard deviation computed to present the variability of the estimate. A statistical analysis of the potential confidence level of each expected value would help determine the sample size of the number of trip observations to be collected.

This model could be simply applied to most travel forecasting software package outputs using application software such as FORTRAN or DBASE. The inputs would be: 1) the estimate of VMT stratified by facility type, 2) the number of weekday hours under which each facility type is estimated to operate with peak and off-peak traffic conditions, and 3) the V/C ratio produced by the traffic assignment model. The output would be VMT stratified into each vehicle operating mode by time of day and geographic location (grid cell).

Cold Start/Hot Soak Model

The purpose of this model is to estimate the fraction of vehicle trips which have cold start and hot soak emissions, which is a function of the time span between vehicle usage for vehicle trips. As is discussed in the emission model section of this report, cold start emissions and hot soak emissions will be a greater percentage of total vehicle emissions for each vehicle

Table 2. Example Vehicle Operating Mode Model

	V/C Range (Based Upon 24 Hr. ADT Assignment)				
Facility Type	0-0.25	0.25-0.5	0.50-0.75	0.75-1.00	1.00+
Freeway	Peak				
	% idle				
	% accel				
	% decel				
	% cruise				
	off-peak				
	% idle				
	% accel				
	% decel				
	% cruise				
Expressway					
Primary Arterial (5+ signals/mi.)					
Primary Arterial (3-5 signals/mi.)					
Primary Arterial (<3 signals/mi.)					
Secondary Arterial (5+ signals/mi.)					
Etc.					

trip in the future as running emissions are further controlled. Hence, being able to estimate the percentage of cold starts and hot soaks based upon the temporal spacing of vehicle usage by trip is deemed important for improved emissions modelling in the future.

The model would estimate the percentage of vehicle trip ends that are cold starts and hot soaks as a function of trip purpose (home-based work (HBW), home-based other (HBO), and non home-based (NHB)) and trip duration. This model would be calibrated from data obtained in a transportation auto use survey in several urban areas, such as that collected by the Metropolitan Washington Council of Governments in their 1968 travel survey. This type of survey asks the respondent to record the usage of each vehicle owned by the household over the course of the day. For each vehicle trip, the following types of information are collected:

- time of trip start
- location of trip start
- time of trip end
- location of trip end
- purpose of trip
- number of persons in vehicle

The model might look like the example in Table 3. The percent of cold starts and hot soaks would be determined based upon the time intervals between vehicle usage. After an hour of non-usage, a catalyst-equiped vehicle will be considered to be in a cold start status when used next. The hot soak emissions will occur at trip end or immediately after the vehicle has been shut off.

The model would be applied to the vehicle trip table input to the traffic assignment model and the output would be the number of vehicle tripends in each traffic analysis zone which are estimated to have cold starts and hot soaks, for both peak and off-peak periods. It could be developed as a stand alone program using FORTRAN or DBASE or could be a "set-up" inside any of the trip table matrix manipulation programs found in all travel forecasting software packages. These tripends would be input to the emission model to estimate the tripend component of emissions which could also be allocated to grid cells based upon the traffic zone in which they lie and using GIS software to perform the allocation.

TCM Impact Model

The purpose of this model is to estimate the vehicle trip reduction effects of various transportation control measures (TCMs) that will likely be implemented by urban areas in an attempt to reduce vehicle emissions and highway congestion.

Table 3. Example Cold Start/Hot Soak Model

		Trip Duration					
		< 5 Min.	5-9 Min.	10-14 Min.	15-20 Min.	20-30 Min.	>30 Min.
HBW	Peak						
	% Cold start						
	% hot soak						
	Off-peak						
	% Cold start						
	% hot soak						
HBO	Peak						
	% Cold start						
	% hot soak						
	Off-peak						
	% Cold start						
	% hot soak						
NHB	Peak						
	% Cold start						
	% hot soak						
	Off-peak						
	% Cold start						
	% hot soak						

These TCMs, also known in the transportation planning profession as travel demand management (TDM) measures, are designed to induce commuters to shift to higher occupancy modes for their work trips. Example TCMs include improved transit or HOV alternatives, parking management and pricing, flexible work hours, guaranteed ride home programs, and carpool and vanpool incentives. Mode choice models and procedures need to be developed which can more accurately predict the mode shifts likely to occur when these TCMs are implemented in urban areas.

These TCM/TDM impact models are already under development in projects being sponsored by agencies such as FHWA, CARB, and Seattle Metro. However, additional refinement is necessary to improve the number of strategies for which these models can predict travel changes. This refinement will come from the collection of additional travel survey data from sites at which the various measures have been implemented, and the calibration of more robust models to these observed data. Additionally, these models will need to be integrated so that one set of models containing all relevant mode choice determinants is produced. These models will also need to be directly integrated into the four step travel forecasting process described above, rather than being used "off-line" as they currently are.

As in current regional mode choice models, these models estimate the commuter's choice of mode as a function of the socio-economic characteristics of the tripmaker, the characteristics of the competing modes of travel, and the characteristics of the employment site. However, these models are constructed to specifically include more factors at the work site, particularly the mode choice effects of a variety of employer-based TCMs and the aggregate mode choice effects of varying levels of employer participation in the provision of these measures. The output of these models is the number of work purpose person trips for each TAZ-to-TAZ movement which are forecast to utilize transit, carpool/vanpools, or drive alone measures.

Macroscale Models of Vehicle Trips and VMT for Areas Outside Urban Cordon

As previously discussed, most urban area travel forecasting models have a coverage area, or cordon area, which covers most, but not necessarily all of the travel shed of the urban area. The cordon area is usually adjusted once every ten years or so, based upon information from the decennial census. Urban airshed regions, however, may be larger than the area covered by the travel forecasting models, causing a problem with being able to accurately estimate mobile source emissions generated within the portion of the urban area that lies within the airshed, but outside the travel forecasting cordon. Procedures need to be developed which allow estimates to be made of vehicular travel in these "unmodeled" portions of the urban area.

These outlying areas, typically entire counties, could have travel estimates developed based upon default models calibrated using national travel data sources such as the National Personal Travel Survey (NPTS) and the Census Urban Transportation Planning Package (UTPP). These models would estimate daily VMT and vehicle trips per household as a function of common socio-demographic and land use variables such as:

- vehicles/household
- workers/household
- persons/household
- average population density
- number of households
- number of employees

and transportation supply statistics such as:

- average lane-miles of roadway/square mile
- average trip length

The specific variables and their statistical relationships would be determined based upon statistical analyses of databases such as NPTS, particularly for exurban counties of urbanized areas. Model inputs, for example, could be county level estimates of households, employment, and highway lane miles, and model outputs would be average weekday VMT and vehicle trips. The relationships (models) might be able to be stratified by urban area population, depending upon how robust the databases are.

The outputs of this aggregate model would augment the results of the four step models for urban areas where the travel forecasting cordon does not cover the entire airshed.

SECTION 4

CONCLUSIONS

ADVANTAGES/DISADVANTAGES

One of the advantages of the model design is its ability to capture the full range of vehicle operating conditions, in addition to its ability to present data at the level of detail necessary to validate and verify results. Previous reliance on the Urban Dynamometer Driving Schedule (UDDS) and Bag 1, 2 and 3 emission values has led us to overlook some of the most severe (and high polluting) driving conditions. These problems are also a function of the limitations of the vehicle testing technologies.

While the proposed design is complex, the issues are also complex, and any method that is designed to estimate the effects of future transportation control measures has to be sophisticated. For example, a decision about whether to spend $10 million for a ramp metering system to reduce highway congestion has to be made with full knowledge of the likely effects. Increasing the number of hard accelerations by making vehicles stop on the ramp may produce more emissions than are being reduced by decreasing congestion and increasing speed on the highway. Evaluations of land use changes and proposed major transportation projects are difficult without sophisticated tools.

Another advantage of the design is that it can build on advances in the state of the art of transportation modeling. DOT-FHWA has planned a number of new studies to ensure that improvement in the next 3 to 5 years and the conceptual design presented here should be able to include such advances.

COSTS

Costs to apply the procedures suggested here are those in addition to costs that States and MPOs will be incurring to apply travel demand forecasting procedures to their areas. We estimate that the incremental cost to apply the vehicle model and cold/hot soak models to be $10 to 20 thousand per area. Modeling TCM impacts will be more involved and could realistically cost as much as $80K per area.

VALIDATION

Our comments on validation are related to city-specific validation of the methods suggested here. Transportation model results are normally validated component-by-component. For example, model split models are validated by travel surveys. Similarly, checks on VMT are from count programs. These

include screen line and cordon line checks by sector. Auto occupancy checks are another form of validation.

On-road vehicle emission tests are not practical with today's sampling technologies, especially for every urban area that needs to prepare an emission inventory. Developing such technologies is a research need. Remote sensing holds some promise. The recently initiated project in the South Coast (CA), along with the other evidence collected to date, should provide a reasonable assessment of its applicability and cost. Tunnel studies are probably too expensive to perform more than once every 3 to 5 years. Until remote sensing proves to be a practical tool for validating motor vehicle emission estimates, we believe that improving I/M program performance and taking advantage of the annual data tracking possibilities is the best validation tool for emission modeling in a 3 to 5 year time frame. I/M data can be useful in validating emission modeling results at various points in the process (as is transportation model validation as described above) including developing registration distributions, tracking mileage driven by vehicle age, and having an alternative source of emissions test data.

Satellite photos are a potential validation tool primarily as a way of noting whether episode day conditions differ significantly from "average daily traffic."

APPENDIX D

CONCEPTUAL DESIGN OF A NEW MOTOR VEHICLE SOURCE MODEL

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ABSTRACT

This report describes Radian's new motor vehicle source (MV) model. The MV model includes procedures to develop travel demand estimates, emission factor modeling and emission estimation. The MV model requires travel demand estimates that treat trip end effects separate from running emissions. Link-specific vehicle hours traveled (VHT) are matched with emission factors that are expressed in units of grams per hour. Each link in the transportation system is characterized by a driving cycle, which is a function of its facility type and area type and level of congestion (on-peak or off-peak). Emission factors are computed for each driving cycle. The Radian/CRC Evaporative Model is used to compute the evaporative emissions component. The MV model will be written using fourth generation language software and take advantage of geographic information system software. It will be menu-driven, user-friendly and modular to allow for easy updating. This model has the following characteristics:

- Fourth generation language software (i.e., SAS® and ARC/INFO®) form the basis of the motor vehicle source model;
- GIS techniques are used to simulate all roadways, including minor collector and residential streets, in a region;
- Origin -- destination trip tables are used to develop hour-by-hour link-specific travel demand estimates;
- Transportation modeling procedures are provided to generate travel demand estimates for both on-network and off-network areas;
- Trip end effects are treated explicitly;
- A driving cycle matrix, by facility type and area type, is used to characterize each link in the region;
- Vehicle hours traveled (VHT) are matched with gram per hour emission factors to develop link-specific emission estimates;
- The transportation model is embedded in and is an integral component of the motor vehicle source model;

PREFACE

This report describes a new motor vehicle source model. The report is divided into seven sections. Section 1.0 includes some introductory material. Those readers familiar with the shortcomings of the current methodology used to develop emission estimates from on-road motor vehicles may want to skip this section and begin with Section 2.0. Section 2.0 provides a brief overview of the new motor vehicle source model. Section 3.0 describes the Transportation Modeling System required to generate the travel demand estimates for this model, including the development of the driving cycle matrix (by facility type and area type). Section 4.0 describes how emission factors will be developed for each driving cycle. Section 5.0 discusses how the travel demand estimates and corresponding emission factors will be combined to develop gridded, speciated, temporally resolved emission estimates. Section 6.0 presents the data inputs required to use this new model. Section 7.0 discusses several techniques that can be used to verify the emission estimates produced by the new model.

- Emission factors, on a grams per hour basis, are developed for each driving cycle in the driving cycle matrix, based upon mode test data;
- Customized driving cycles for specific applications can be developed.
- Evaporative emissions are modeled using the Radian/CRC evaporative model;
- Alternative fuels are accommodated; and
- Emission estimates can be gridded into a variety of grid structures, including uniform, variable and nested grids.

The report summarizes the shortcomings in the current methodology used to develop motor vehicle emission estimates. A list of required model inputs is provided. Detailed discussions of all of the model components are provided, along with techniques that can be used to verify the resulting emission estimates.

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1.0 INTRODUCTION

The development of cost-effective air pollution control strategies that will achieve federal and state ambient air quality standards (AAQS) requires accurate estimates of emissions from applicable source categories. Volatile organic compound (VOC), nitrogen oxide (NO_x) and PM_{10} emissions from on-road motor vehicles continue to make-up a major portion of the total emissions inventory from these pollutants in most areas of the nation, many of which are currently exceeding AAQS. In addition, on-road motor vehicles emit significant quantities of toxic air pollutants (e.g., benzene). Consequently, accurately quantifying VOC, NO_x, PM_{10} and various specific toxic compounds from on-road motor vehicles will play a critical role in the development of various air pollution control programs. Recent studies indicate that current procedures for estimating emissions from on-road motor vehicles significantly underpredict observed values. Furthermore, it is doubtful that existing methodologies will be able to properly treat alternative fuels, new vehicle technologies and transportation control methods that will be available in the near future. It is imperative that new procedures be developed to more accurately estimate emissions from on-road motor vehicles. The following discussion presents the conceptual design of a new motor vehicle source model to estimate emissions from this source category.

1.1 Shortcomings of Existing Methodologies

The methodology used to develop emission estimates from on-road motor vehicles can be expressed in simple terms as the processing of age-composited emission factors for the various classes of vehicles for the year of interest, along with spatially and temporally distributed travel demand estimates, to produce emission estimates for a given region. These estimates may be gridded, speciated and temporally resolved depending upon their desired use. Each of these components (i.e., emission factor development, generation of travel demand estimates and emissions modeling) currently

has some severe shortcomings. Some of the most important limitations of the current procedures are described below.

1.1.1 Travel Demand Estimates

Although many different types of transportation models (e.g., MINIUTP, UTPS, System II, EMME-2) are used to develop travel demand estimates in urban areas, these models can be divided into the following six general categories:

- Development of socioeconomic/demographic data;
- Trip generation;
- Network development;
- Trip distribution;
- Mode choice; and
- Trip assignment.

Uncertainties and potential errors in the magnitude of the emission estimates based upon the use of vehicle activity data from current transportation models, as well as the spatial and temporal disaggregation of these values, may be introduced at each step of the transportation modeling system (TMS) process. Examples of these uncertainties are described below.

Socioeconomic/Demographic Data. The development of socioeconomic and demographic data is an important component of the TMS and actually drives the process. This information is typically provided by land use forecasts of the modeled region and the socioeconomic characteristics of its inhabitants (e.g., number of households by income level, population and employment characteristics of the residents of the region). Many areas of the nation, (e.g, the South Coast Air Basin [SoCAB] in Southern California) have been rapidly growing and although forecasts may be made as often as every five years, this may not be adequate for the purposes of transportation

modeling. In addition, and perhaps more importantly, accurate future year socioeconomic and demographic forecasts would be even more difficult to make, especially those that are 20 years into the future.

Trip Generation. Trip generation involves developing estimates of the rates of trip productions and trip attractions for discrete areas, usually identified as travel analysis zones (TAZ). Each trip can be visualized as being produced in one TAZ and attracted to another. A significant portion of the VOC emissions from on-road motor vehicles (i.e., the evaporative emissions), are directly proportional to the number of starts (origins) and parks (destinations) in a given TAZ. The starts are further broken down into cold starts and hot starts, and the emissions during the park period are a function of the number of hours a vehicle is parked before it is re-started. In order to accurately quantify and locate these "trip end" emissions in a region, it is necessary to accurately determine the number of origins and destinations in each TAZ. In addition, errors in the calculation of trip productions and attractions will lead to errors in the quantification of vehicle miles traveled (VMTs).

There is reason to believe from recent studies that trip generation rates in various urban areas, such as the SoCAB, have been changing over time due to the changing nature of the inhabitants of a given region. While average household size has been decreasing, trips per household have increased due to the ever increasing number of two-worker households. Increased vehicle ownership in recent years also contributes to a greater number of vehicle trips per household. While trip generation models account for some of these changes in trip generation rates, the data and assumptions that are used in the models need to be periodically updated. Trip generation models are based upon a combination of regression analyses of certain demographic and socioeconomic characteristics that yield trip making units, which are converted into person trips by applying trip generation rates. The trip generation rates are developed from survey data and define the number of person trips generated by a particular kind of housing unit having a given level of vehicle ownership, for a specific trip purpose. A

similar process is used to develop estimates of trip attractions. The use of regression techniques and outdated survey information (travel surveys in most urban areas have not been updates since the late 1960's or mid-1970's due to the associated costs of obtaining and analyzing this information) may introduce considerable uncertainties in the development of trip productions and attractions. The fact that these rates are typically assumed to be constant throughout a given county may not properly account for socioeconomic and demographic differences that may exist across certain counties in a given region, such as the SoCAB.

Another concern in the development of trip productions and attractions is how large trip generators, such as airports, are handled in the trip generation model. The TMS used by most transportation modelers does not appear to treat these large trip generators separately; therefore, the attractiveness of large trip generators are typically simulated by their employment characteristics, which may significantly underestimate the attracted trips for the TAZs containing these large trip generators. Also, episodic travel events (e.g., concerts, baseball games, etc.), are not properly included in the trip generation model.

In addition, trip productions and attractions are generated for a typical weekday and do not reflect differences in travel patterns that occur during various seasons in different parts of the nation (e.g., winter and fall in New England, summer in the SoCAB) or on weekends. Several types of trips, such as work and school trips, are reduced during the summer months, while agricultural and recreational trips increase during these warmer periods. The use of average weekday productions and attractions may introduce significant uncertainties in the generation of trip productions and attractions during other periods.

Trip Distribution. The next step in the TMS process is trip distribution, which connects zonal productions with attractions. Productions are typically distributed among all available attractions in a region in proportion to the size of the attractions in

each TAZ and inversely proportional to the distance or travel time between the production and attraction using the so-called "gravity model." The distance variable in the trip distribution model is computed using a path-building algorithm that is based upon travel time. The resulting matrix of directionless trips between TAZs may be converted into a matrix of origins and destinations by using the ratio of the production to attraction movement to the origin and destination information obtained from trip surveys. These origin and destination surveys are badly outdated in most regions (e.g., the trip generation model in the SoCAB was last updated with travel survey data collected in 1976). Therefore, considerable errors may be introduced in properly locating these trip ends in a given region.

Trip ends are used to compute emissions from cold start/hot start (by technology type, e.g., catalyst equipped vehicles, etc.) and parks (hot soaks and diurnals) in California. EMFAC, the emission factor model used in California, treats these trip end effects separately from running emissions. However, MOBILE4, the emission factor model developed by EPA and used in the rest of the nation, treats all emissions proportional to VMT. This is accomplished by assuming an average number of trips per vehicle per day and miles per vehicle per day for a given region. MOBILE4 contains default values for these parameters. Although the user can supply region-specific estimates, this is rarely done. The use of average default values in MOBILE4 has the potential to introduce significant errors in the calculation of these emission components. In addition, distributing these emissions on a per mile basis (instead of the grid cell in which the emissions occur) results in spatial allocation errors.

The development of transit facilities and the encouragement of ridesharing in many areas may make it difficult to forecast future year travel demand estimates based upon current travel patterns, particularly for work trips. Consequently, there is considerable uncertainty in the accuracy of travel demand estimates, particularly for periods well into the future (i.e., the years 2000 and 2010), and the corresponding on-road motor vehicle emission estimates that are a function of these travel characteristics.

Trip Assignment. After trips have been distributed between TAZ, they are assigned to specific links on the highway network. In most urban areas this assignment is done on a daily basis, although some regions, such as the SoCAB, may make separate trip assignments for the AM and PM peak periods. Capacity restraint techniques, particularly for peak periods, are one of several procedures that may be used to assign trips to specific roadways. Factors which affect capacity restraint assignment are uncongested link speeds, link volume capacities, and the relationship between volume to capacity (V/C) ratios and congested speeds. Speed on a given link is a function of the V/C ratio of the link and the associated free flow speed. This relationship can be simulated by many different types of functions. This, along with the fact that a single assignment is performed for the entire day, makes the determination of the average vehicle speed for a given link (and especially for a given hour of the day) very suspect. Since on-road motor vehicle emission estimates are sensitive to changes in vehicle speeds, the fact that hourly link-specific vehicle speeds are not developed is a shortcoming of the TMS process and may introduce considerable uncertainty in the development of emission estimates.

TMS Calibration and Verification. Calibration and verification of the trip assignment model is less straightforward than the other portions of the TMS process due to a lack of a single variable that can be adjusted to bring predicted and observed data into agreement. In addition, highway trip assignment includes the errors occurring in other parts of the TMS process. The indicator commonly used to assess the accuracy of the highway assignment process is a comparison of estimated and observed link traffic volumes. VMT is computed by multiplying link volumes or traffic counts by the link distance and summing over all links. VMT comparisons primarily reveal systemwide inaccuracies in the TMS process. For example, total regional estimated VMT may differ from observed VMT totals. This probably indicates an error outside of the highway assignment model, such as incorrect trip generation values from the trip generation model, trip lengths obtained from the trip distribution model, or mode shares from the

mode choice model. Improper calibration may introduce additional uncertainties in the travel demand estimates produced by the TMS.

1.1.2 Emission Factor Models

On-road motor vehicle emission factors are determined by a complex process that considers the characteristics of the vehicles involved, as well as the conditions under which they are operated. Uncertainties exist in the manner in which the current emission factor model treats variations in speeds, temperatures, super emitting vehicles, certain evaporative emission effects (e.g., running losses, resting losses), and off-FTP cycle operations, as well as some of the inputs into the model (e.g., registration distributions, mileage accumulation rates).

Registration Distributions and Mileage Accumulation Rates. Application of MOBILE4 and EMFAC7E requires, as inputs, registration distributions and mileage accumulation rates by model year for each vehicle type. Currently, while registration distributions and mileage accumulation rates will vary depending upon the calendar year being modeled, application of both models (i.e., MOBILE4 and EMFAC7E) typically involves the use only one set of registration distributions and mileage accumulation rates for all regions. Variations in the registration distributions by region could impact the resulting emission rates. This could be particularly important in certain parts of the nation, such as the SoCAB, where excellent climate allows older, high polluting vehicles to remain on the road longer. Recent research has shown that the use of alternate distributions and rates can alter the resulting emission factors by approximately 10 percent for light-duty gasoline vehicles.

Speed Corrections. For emission factor calculations, speeds on individual links are determined from transportation models as discussed above. These are checked against roadside survey data to determine the accuracy of the estimates. The accuracy of these speed estimates are important because both MOBILE4 and EMFAC7E show

considerable sensitivity to variations in average speed, particularly at extreme high and low speeds.

Temperature Corrections. For forecasting of emission impacts in a given region, spatially resolved hour-by-hour temperatures are typically unavailable for use in calculating emission factors. In certain regions of the nation, such as the SoCAB, temperatures can vary significantly from one hour to another and from one part of the region to another. Given the non-linear characteristics of the temperature correction factors in both MOBILE4 and EMFAC7E, this could lead to inaccuracies in the predicted emission factors, especially if spatially and temporally resolved emission estimates (required as inputs to photochemical models) are desired.

Running Losses. The current methodology for calculating running losses in both MOBILE4 and EMFAC7E is based upon testing of 47 vehicles sponsored by EPA. The 47 vehicles were tested under a variety of temperatures and driving cycles. The results from these 47 vehicles have been used to cover all model years of light-duty gasoline automobiles and trucks.

Although EPA uses the same test data for calculation of running losses in MOBILE4 as ARB does in EMFAC7E, EPA's calculation methodology differs from ARB. According to ARB's documentation of EMFAC7E, ARB conducted a statistical analysis and found significant effects of speed and temperature on running losses. EPA assumes that running losses also vary with temperature, but that they are constant with speed. ARB's methodology has running losses at a maximum at idle and decreasing linearly down to zero at 45 miles per hour. At lower speeds and lower temperatures, the difference between ARB's and EPA's methodologies are not significant. At higher speeds and higher temperatures, the difference increases and EPA's running losses are significantly greater than ARB's. For example, at 95°F, the difference between MOBILE4 and EMFAC7E ranges from 0.05 gram/miles at 2.5 miles per hour up to 1.0 gram/mile at 45 miles per hour and above.

Resting Evaporative Emissions. Resting evaporative emissions are emissions that escape from the fuel or evaporative control system as a result of permeation through various non-metallic fuel system sources, or as a result of vapor migration allowed by other system design features, such as open-bottom canisters. Resting evaporative emissions represent a potentially significant new class of ROG emissions. They have not been accounted for in the past because evaporative emissions tests were too short in length to detect them. The new, longer evaporative emissions test procedure adopted by ARB will facilitate measurement of resting losses. At the present time, however, data to fully quantify resting losses are not yet available. Therefore, the current estimations of their impact are very imprecise. Recent research indicates a range of possible resting loss emission factors from 0.07 grams/mile to 1.02 grams/mile. A resting loss emission rate of 1.02 grams/mile would equate to an increase of 37 percent in VOC emissions for on-road motor vehicles in the SoCAB (using EMFAC7E) based on gasoline VMTs of 225,709,000 miles per day.

Evaporative Control System Failure Rates. EPA recently released data from testing of evaporative control systems during a short duration loaded dynamometer test. The tests evaluated the system's ability to hold vapors under pressure and to properly purge vapors under vacuum conditions. Analysis of the data showed that the control system failure rates were significantly higher than previously believed.

Data released by EPA showed a minimum 20 percent increase in total evaporative emissions. The overall effect on emissions in various regions is not clear given the confounding effect of an I/M program. A rough estimate showed that the minimum 20 percent increase in evaporative VOC emissions would lead to a 6 percent increase in overall on-road motor vehicle VOC emissions.

Super Emitters. The emission factor model used by EPA groups vehicles in emitter categories, from normal emitters that are at or below the emissions standards, up to high and super emitting vehicles that emit at many times above the standards. The

highest emitting vehicles, super emitters, represent an important group of vehicles for calculation purposes. They do not represent a large portion of the vehicle population, but their effect is magnified by their high emission rate, especially for VOC. While VOC and NO_x emission rates all increase as emission control systems deteriorate, VOC also increases further when engines fail to maintain optimum air/fuel ratios, which can occur due to vehicle aging or lack of maintenance. NO_x emissions will decrease when engines are operated under non-optimum air/fuel ratios.

Both MOBILE4 and EMFAC7E are quite sensitive to the emission rate and growth of the super emitting vehicle population. Given a 20 percent increase in the base super emitter emission rate in EMFAC7E, an increase of 6 percent in VOC is seen in the overall light-duty automobile (LDA) emission factors. If the super emitter growth rate is increased by 20 percent, LDA VOC emission factors are increased by 4 percent. NO_x emissions are not as sensitive to the growth in super emitters, since NO_x emissions are promoted by higher combustion temperatures in properly running engines. Analysis of EMFAC7E showed that a 400 percent increase in the super emitter growth rate would result in a 50 percent increase in the LDA ROG emission factor and a 30 percent increase in the NO_x emission factor. A 400 percent increase in super emitter growth rates should be considered a worst-case scenario. Assuming a 400 percent increase in super emitter growth rate and a 20 percent increase in base super emitter emission rates, the LDA VOC emission factor would increase by almost 60 percent.

Off-FTP Cycle Operations. The impact of vehicle operation outside of the FTP75 procedure on VOC emissions could represent a large source of error in the on-road motor vehicle emissions inventory. While the FTP75 cycle is a transient procedure that includes many accelerations, and consequently higher engine loads, it has been noted that the procedure does not include severe acceleration rates often encountered in normal vehicle operation. Accounting for operation outside of the FTP cycle could be important to accurately determining in-use vehicle emissions. Knowledge of actual driving conditions and their relationship to the FTP75 procedure becomes important.

Recent work by ARB confirms that variations in engine speeds and loads outside of those represented in the FTP75 procedure could significantly impact VOC emissions.

At this point in time, it is not possible to estimate the impact of differences in off-FTP cycle operation on the overall emissions inventory. Clearly, operation outside of the FTP75 conditions could significantly affect the accuracy of on-road motor vehicle emission estimates.

Trip End Effects. As was stated above, MOBILE4 treats trip end effects (i.e., cold start/hot start emissions, hot soak and diurnal evaporative emissions) proportional to VMT, while EMFAC handles these emissions on a per trip (i.e., start or park) basis. The potential errors introduced by the MOBILE4 methodology have already been discussed above.

1.1.3 Emission Estimation Methodology

Currently, the procedures available for combining travel demand estimates and emission factors into emission estimates are limited, particularly for developing speciated, temporally and spatially resolved values for input to photochemical models. California has developed two emissions models for this purpose- the Direct Travel Impact Model (DTIM) and BURDEN. DTIM was developed by ARB and the California Department of Transportation (CALTRANS) to develop gridded, speciated, hour-by-hour emission estimates for input to a photochemical model. DTIM uses travel demand estimates generated by a TMS (i.e., hourly link-specific VMT and speed estimates and TAZ trip end estimates) and EMFAC-derived emission factors. Although DTIM provides the user with a great deal of flexibility, it is written in FORTRAN and is a very difficult program to use. DTIM would have to be substantially modified to use emission factors generated by MOBILE4. DTIM is not user-friendly and requires several model runs to develop hour by hour emission estimates. In addition, DTIM will not easily handle variable size grid cells or a nested grid structure.

ARB uses BURDEN to calculate on-road motor vehicle emission estimates on a regional (e.g., county) basis for those areas that are not covered by TMS. BURDEN estimates the number of vehicle trips in a given region, along with the hot start/cold start splits and the associated VMT. Emission factors are obtained from EMFAC and used to compute regional emission estimates. In this manner, motor vehicle emission estimates are treated as an area source and spatial surrogates (e.g., population, length of road) are required to spatially allocate these emissions to grid cells. Generic temporal profiles are used to develop hour-by-hour emission estimates.

Models similar to DTIM and BURDEN are typically not available for use with MOBILE4. Most states use crude procedures to match regional estimates of VMT with MOBILE4-derived emission factors to calculate on-road motor vehicle emission estimates. Most areas do not directly use the output of TMS to develop link-specific emission estimates and, therefore, software to compute these emission estimates in that manner is not readily available.

2.0 BRIEF OVERVIEW OF A NEW MOTOR VEHICLE SOURCE MODEL

The new motor vehicle source (MV) model proposed by Radian Corporation is based upon the development of a matrix of driving cycles and the characterization of each link (by facility type and area type) in the transportation system according to the driving cycle that best fits its particular use. Trip end effects are treated separately from hot stabilized operation. Emission factors will be developed for each driving cycle on a per-hour basis, based upon the use of a separate modal analysis model. Alternative fuels will be accommodated. The modular nature of the MV model will make it easy to substitute updated emission factors and driving cycles as vehicle technology and vehicle usage change over time.

The MV model will generate hour-by-hour link specific emission estimates for urban areas, based upon the development of travel demand estimates obtained from a TMS designed specifically for air quality-related analysis (i.e., on-network travel demand estimates). The new TMS will accommodate large trip generators and also be able to handle micro-scale changes in travel demand estimates resulting from the implementation of transportation control measures.

The MV model will also accommodate travel demand estimates developed for rural areas for which the TMS will not be run. These travel demand estimates will be distributed on the transportation network obtained from the TIGER/Line data and treated in the same manner as on-network generated estimates.

The MV model will be user-friendly and be able to produce speciated, gridded, temporally resolved emission estimates for input to a photochemical model. The MV model will also be designed to facilitate projections of future year travel patterns and emission estimates and various sensitivity analyses. This new MV model would require a five (5) to 10 year timeframe for implementation.

A schematic diagram of the new MV model is depicted in Figure 2-1.

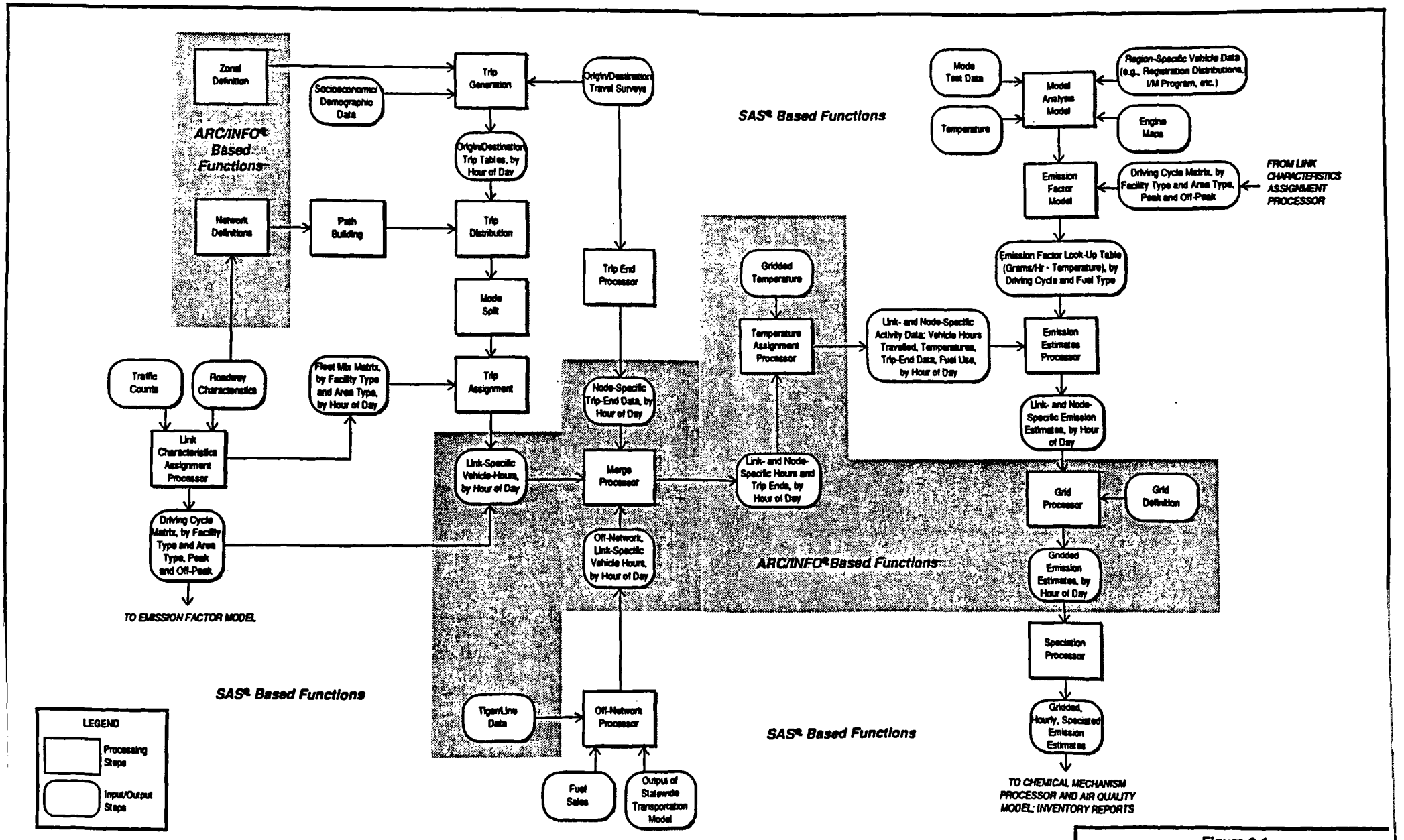

Figure 2-1.
New Motor Vehicle Source Model.

3.0 DEVELOPMENT OF TRAVEL DEMAND ESTIMATES

Currently, a diverse range of methodologies are being used to develop estimates of vehicle miles traveled (VMT) and speeds in urban areas, resulting in a wide range of accuracies. TMS have been designed to develop regional travel demand estimates and, accordingly, do not handle variations in link-level traffic operations during peak congested conditions very well. Emphasis is generally on planning for major corridor-level projects and on forecasting traffic volumes on major roadways. Considerably less importance is placed on air quality planning needs such as travel speeds, particularly for minor collectors and residential streets.

Many urban areas do not even use a TMS but develop regional travel demand estimates based upon traffic count data, fuel sales or a hybrid approach. Since MOBILE4 treats trip ends proportional to VMT, no attempt has been made outside of California to develop accurate estimates of starts and parks and their distribution (both spatial and temporal) for a given region. In order to produce accurate travel demand estimates for Radian Corporation's new motor vehicle (MV) source model, a new type of TMS, which emphasizes generating the travel demand estimates required to drive this model, must be developed. The following discussion discusses how such a TMS might be structured.

3.1 Driving Cycle Matrix (by Facility and Area Type)

The Federal Test Procedure (FTP) was developed by EPA to certify that passenger cars comply with applicable federal emission standards. Current emission factor models (MOBILE4 and EMFAC) rely on FTP-based emission estimates, corrected for varying average speeds and temperatures. However, in-use driving patterns can vary dramatically from the FTP cycle, particularly the number of accelerations/decelerations associated with a particular driving cycle. Speeds greater than 48 mph are not even included in the FTP. MOBILE4 only includes speeds from 5 to 55 mph. The model

proposed by Radian will be based upon the development of emission factors, on a grams/hr basis, for a pre-determined number of driving cycles or a driving cycle -- emission factor matrix for different combinations of roadway facility types (e.g., freeway, expressway, etc.) and area types (e.g., central business district [CBD], rural, entrance/exit ramp, etc.). This matrix will be stratified by peak and off-peak travel periods. Each link in a given transportation network will be classified according to its use and matched to a particular driving cycle and corresponding emission factor.

The vehicle distribution associated with each facility type/area type combination in the driving cycle matrix, must also be developed on an hourly basis, along with the diurnal distribution of weekday (and weekend) trips. This information can be obtained by instituting a comprehensive and statistically valid traffic count program designed around the driving cycle matrix. Additional information regarding link-specific vehicle distribution data will be obtained from satellite imagery. At a scale of 1:400, it is possible to count traffic and at a scale of 1:100, it is possible to discern passenger cars from trucks, and it might be possible to actually further resolve vehicles by type (other than just cars and trucks), using improved computerized data reduction techniques.

The possible facility types that will be part of Radian's proposed TMS model include the following classifications:

- Freeway;
- Expressway;
- Major arterial;
- Minor arterial;
- Major collector;
- Minor collector;
- Residential streets; and
- Entrance/Exit ramps.

The first five (5) classifications are typically coded into the highway network currently used in TMS. Minor collectors and residential streets are not usually accounted for in a typical transportation network model, but will be included in Radian's model. Vehicle activity on these types of links typically account for, 10 to 15 percent of low speed, congested, stop and go traffic volume in a given urban area. However, the low speeds and congested nature of travel on these surface streets makes these roadways significant sources of vehicle emissions. Radian's TMS will take advantage of the increased storage capacity and processing speed of today's (and tomorrow's) computers and geographic information system software (GIS) to expand the transportation network to include vehicle activity on minor collectors and residential streets.

Entrance and exit ramps will also be explicitly included in the TMS due to the large amount of vehicle emissions generated during accels and decels. This is especially true of metered entrance ramps. Inclusion of entrance/exit ramps in the driving cycle matrix will be an important additional facility type that has been typically excluded from existing network models.

The possible area types that will be part of Radian's proposed TMS model include the following classifications:

- Central Business District (CBD);
- Urban;
- Residential;
- Commercial;
- Suburban; and
- Rural.

Comprehensive traffic count programs will be developed to support the construct of the driving cycle matrix. The traffic counting program will include the use of permanent embedded counters that are able to transmit data directly to a central

computer system for reduction, analysis and storage. These embedded counters will be supplemented with traditional counters, video recorders of selected roadways (for vehicle classification identification) and data obtained from satellite imagery.

Driving cycles that best characterize each facility type/area type combination will be developed. These driving cycles will form the foundation for the development of emission factors, on a grams/hr basis, as described in Section 4.0. Table 3-1 presents an example of a possible driving cycle matrix by facility type and area type.

3.2 Origin -- Destination Travel Surveys

The cornerstone of any TMS is comprehensive and current origin -- destination travel survey data. These data, along with the demographic and socioeconomic characteristics of the residents in a particular region, form the basis of the trip generation models that produce the trip generation rates that drive the TMS. Current trip generation models used in TMS generate trip productions and attractions by traffic analysis zones (TAZ).

Trip generation estimates (i.e., trip productions and attractions) are normally made for an average weekday for each TAZ and are independent of trip direction, length, and duration. The following five trip types are used in the South Coast Air Basin (SoCAB), for example, and illustrate the type of trips that are typically considered:

- Home-other;
- Home-work;
- Home-shop;
- Other-work; and
- Other-other.

Table 3-1

Driving Cycle Matrix
Mode Distributions by Facility Type and Area Type

	Facility Type							
Area Type	Freeway	Expressway	Major Arterial	Minor Arterial	Major Collector	Minor Collector	Residential Streets	Entrance/ Exit Ramps
Central Business District (CBD)	11*	12	13	14	15	16	17	18
Urban	21	22	23	24	25	26	27	28
Residential	31	32	33	34	35	36	37	38
Commercial	41	42	43	44	45	46	47	48
Suburban	51	52	53	54	55	56	57	58
Rural	61	62	63	64	65	66	67	68

* *ij* matrix cell address for: Driving cycle (peak)*ij*
Driving cycle (off-peak)*ij*

The first three trip types listed above refer to trips that either start or end at the home, e.g., the home work trip encompasses the trip from home to work in the morning and the return trip from work to home in the evening. The two trip types classified as other-work and other-other are trips that neither start nor end at home. The other-work trip is a trip that either starts or ends at work, but does not involve the home as a beginning or end point. The other-other trip is a trip that neither involves the home nor the work location.

A trip production is defined as the home end of a home-based trip or the origin of a non-home-based trip. Similarly , an attraction is defined as the non-home end of a home-based trip, i.e., the "work", "shop" or "other" end of a home-based trip. The "other" end of the other-work trip is defined as the production end and the "work" end as the attraction. The other-other trips are usually split evenly into productions and attractions.

Each trip can be visualized as being produced in one TAZ and attracted to another. A significant portion of the VOC emissions from on-road motor vehicles (e.g., evaporative emissions), are directly proportional to the number of starts (origins) and parks (destinations) in a given TAZ. The starts are further broken down into cold starts and hot starts, and the emissions during the park period are a function of the number of hours a vehicle is parked before it is re-started. In order to accurately quantify and locate these "trip end" emissions in a given region, it is necessary to accurately determine the number of origins and destinations in each TAZ, not productions and attractions.

The Radian TMS will be based directly on origin -- destination data and will not convert these data into productions and attractions for subsequent distribution (as is typically done in today's TMS using the so-called "gravity" model). In addition, the information gathered in these surveys will be modified to include time of day information, preferred route of travel for each trip, use of alternative fuels, vehicle class and technology type, and an estimate of the time a vehicle is parked before it is re-

started. The surveys will be expanded to include information on commercial travel, which is currently not handled properly in trip generation models. In addition, more comprehensive data regarding truck traffic will be gathered so a comprehensive trip generation model can be developed. These data, along with socioeconomic and demographic data obtained from the TIGER/Line data (TIGER/Line Data contain cartographic representations of different geographic features, such as census tract boundaries, which include census statistics), will be used to construct new trip generation models that produce origin (starts) and destination (parks) data for each TAZ by:

- Time of day;
- Day of week;
- Vehicle class and technology type;
- Park duration; and
- Fuel type.

Information will also be gathered to determine if a significant amount of "short trips" (e.g., moving one car out the way so another can leave in the morning, driving around parking lots, moving from one location to another in a shopping mall, etc.) are typically generated. These trips, which are not included in TMS, may significantly contribute to motor vehicle emissions. These data will also be used to develop a trip distribution model that estimates trips between and within a TAZ, by hour of the day and fuel type, based directly on origin -- destination travel survey data.

These comprehensive origin -- destination surveys will be conducted every three to five years, except in high growth areas like the SoCAB, where yearly surveys may be required.

These surveys could either be included as part of permit requirements for industry, e.g., both new construction and operating permits and operating permit renewals (such as those required under Title V of the 1990 Clean Air Act Amendments),

new permit requirements for major trip generators (e.g., shopping malls, airports) or additional permit fees assessed on existing pollution sources (keyed to the number of employees). A computerized survey could be designed to facilitate the analysis of these data. It might be possible to add questions regarding the use of certain consumer products to gather activity data to produce more accurate area source emission estimates, which will help justify the cost/effort of conducting these surveys. One of the national bulletin boards, such as PRODIGY® might be elicited to add an origin -- destination/fuel use survey to their product line as a public service. Local/national environmental groups could be used to gather this type of information, especially if questions regarding the use of public transportation were added. And finally, computerized software could be developed as part of a national/local educational campaign and used by students to query their parents and supply the information to their local air pollution control agency on magnetic media (e.g., floppy disk).

Results of these surveys could be published and, given the current state of environmental awareness, all who participated in gathering this information would become part of the solution to local air quality problems. Local business and industry could be solicited in a cooperative effort to develop the software needed to make this survey "fun" to complete and cost-effective, a sort of "environmental census." Although origin --destination surveys are expensive, they are critical to the development of a TMS that is more tuned to providing more accurate on-road motor vehicle estimates. There are numerous ways, some of which have been suggested above, to cost-effectively carry out these surveys.

3.3 Transportation Modeling

Separate procedures will be developed to treat urbanized areas (i.e., on-network travel demand estimates) and rural regions (i.e., off-network travel demand estimates) as described below. The resulting TMS will be embedded in the motor

vehicle (MV) source model to allow for integration of travel demand estimation, emission factor modeling and the development of emission estimates.

3.3.1 On-Network Transportation Modeling

Current TMS used in urban areas include the following component models as described earlier:

- Trip generation;
- Network development;
- Trip distribution;
- Mode choice; and
- Trip assignment.

As was stated above, the updated origin -- destination travel survey information will be used to develop new trip generation and distribution models that are based directly on origin and destination information. The trip generation and distribution models will account for trips generated by commercial travel, including trucks, trips on minor collectors and residential streets, and external trips (trips that exist outside of the region of interest and either pass through the region or end in that area). These models will be developed in fourth-generation software, such as SAS®, to facilitate the analysis of the origin -- destination travel data and the development of the algorithms needed to accurately develop trip generation and distribution rates.

The network configuration will be developed using GIS software, such as ARC/INFO®, to allow for the modeling of all streets (including minor collectors, residential streets and on/off ramps). Modern computer technology, with its increased storage and processing power, will allow for this expanded network configuration. This will facilitate the subsequent assignment of all trips to links, which will be categorized according to the driving cycle matrix classification scheme described above.

Trip assignments will be made on an hourly basis, for each fuel type used in a given region. The updated origin -- destination travel surveys will provide the detailed data required to make hourly assignments, by fuel type. Instead of VMT, the output of the assignment model, which will also be coded in SAS®, will be vehicle hours traveled (VHT) on each link (by time of day and fuel type). Travel times instead of average link speeds will be modeled to calculate vehicle hours on each link. Travel times are probably more accurate than average link speeds and the emission factor model that will be required, which is described below, will generate emission rates on a grams/hr basis instead of grams/mi. Current techniques based upon the use of speed corrections require link-specific speed estimates. However, the capacity restraint techniques that are used to manipulate link speeds do not necessarily represent accurate speed estimates for a given segment, but rather a value that optimizes traffic assignment over the entire "congested" network. Link-specific travel times are easier to predict and gram/hr emission rates, for links by facility type/area type combinations in the driving cycle matrix, will be more uniform than those based upon grams/mi values.

The use of origin -- destination travel data to build the TMS will facilitate the development of hourly trip end information. The updated survey information will also provide the data necessary to more accurately determine cold start/hot start splits and park durations (by time of day and day of week). A separate SAS®-based module will be developed to manage trip end data. The emission factor model recommended by Radian will treat trip ends separately from running emissions (by fuel type). Trip end emissions will be associated with the centroid of the traffic analysis zone (TAZ) in which the corresponding trip origins and destinations occur. The emissions model described below will allocate the trip end emissions to the appropriate grid cell(s).

Micro-Scale Transportation Modeling. Radian's proposed TMS will be constructed to better handle the micro-scale changes in travel demand resulting from the addition of relatively large trip generators (e.g., shopping malls, civic centers). This same model must also better accommodate the benefits resulting from instituting various

transportation control measures (TCMs). While techniques currently exist to estimate the change in travel demand resulting from the implementation of various TCMs, these micro-scale models are not currently incorporated into current TMS. Radian's TMS will be developed in a manner that allows these micro-scale transportation techniques to be directly incorporated into its TMS, using a nested TMS approach. The TMS user will be able to first run the TMS and then select an area for micro-scale analysis using the results of the TMS as boundary condition inputs to the micro-scale model. The micro-scale model will then be run and the resulting link-specific changes in travel demand will be input into the network configuration that comprises the TMS. This procedure will be facilitated by incorporating the minor collectors and residential streets in the TMS. This will allow the air quality/transportation specialist to accurately analyze the effects that various types of TCMs or trip generators might have on travel demand in the modeled domain. These changes in travel demand will be matched with the appropriate emission factors and the emissions processor will calculate emission estimates for comparison purposes.

3.3.2 Off-Network Transportation Modeling

The TMS described above will be used for most urban areas. However, there will be considerable portions (the more rural areas) of a given region that will lie outside of the area that will be covered by the TMS. In most instances, it will not be cost-effective to develop detailed origin -- destination data for these areas as they contribute a small percentage of the total trips in a given region and the nature of travel in these rural areas (i.e., free flow) is such that emissions are minimized under most circumstances. Therefore, a separate type of transportation modeling procedure, described below, will be developed to estimate vehicle activity for this "off-network" travel.

Travel demand estimates can be obtained in the off-network areas by developing a relationship between fuel sales and vehicle activity. This relationship can

also be used for quality assurance purposes, particularly in regions where multiple fuels will be used. For example, gasoline sales are tracked at the state level for tax purposes and fuel marketing-specific information at the station level may be available from state Leaking Underground Storage Tank (LUST) programs or from the individual stations, through the use of the TIGER/Line data and surveys. Statewide transportation modeling is another potential source of the off-network vehicle activity data. Although statewide transportation models typically include major roadways (e.g., freeways and expressways), the amount of travel on minor roadways in rural areas not covered by the statewide system is of lesser importance. VMT data can be converted to VHT by assuming an average free flow speed. Trip end information could be obtained from the results of statewide surveys or extrapolated from results obtained from origin -- destination travel surveys conducted in the more urbanized areas.

Off-network travel demand estimates will then be allocated to the major roadways in the off-network region using the transportation system included in the TIGER/Line data and using GIS techniques. The area defined by the on-network transportation model will be removed from this "pseudo transportation network" and off-network vehicle activity will be allocated to these "pseudo-links" based upon the ratio of the link-specific road length to the total length of roads that comprise the pseudo off-network configuration. Once travel demand has been allocated to links, temporal profiles will be used to develop hourly estimates and fuel type sales will be used to develop fuel-specific activity data. These off-network travel demand estimates will then be treated in the same manner as the on-network generated data.

A separate driving cycle will be developed to characterize driving patterns on the off-network roadways. Corresponding emission factors will be generated for this driving cycle and the same emissions processor will be used to develop gridded, speciated, temporally resolved emission estimates. These off-network procedures could also be used in urban areas that are unable to conduct the necessary origin -- destination

travel surveys needed to develop the TMS described earlier and the associated detailed travel demand estimates.

4.0 EMISSION FACTOR MODEL

On-road motor vehicle emission factor modeling is currently based on a database developed primarily for vehicle emissions certification, not emissions modeling. Consequently, these data have required extensive modifications and additions to allow the database to cover the wide range of operating conditions experienced by in-use vehicles. Recent research has pointed towards limitations imposed by the use of this database and the need for development of additional data devoted to emission factor estimation.

Some of the areas of emission factor modeling which need improvement include:

- The impact of off-FTP cycle operations and improvement of the model's ability to handle a wide variety of operating conditions. Recent research by ARB and others indicates operation outside of the conditions of the FTP can significantly impact emissions.

- Improve procedures within the motor vehicle emissions model to account for vehicle speeds, and ambient temperatures. Both MOBILE4 and EMFAC7E show significant sensitivity to the accuracy of speed and temperature predictions.

- The potential impact of super emitting vehicles. Both MOBILE4 and EMFAC7E are sensitive to the population and emission rates of this small subset of the vehicle fleet.

- Further investigation into resting evaporative losses. Research is needed to quantify the impact of these emissions and to include them in future emission factor models.

- Incorporation of revised evaporative control system failure rates. Data from testing by EPA show significantly increased evaporative hydrocarbon emissions due to pressure and purge failures of current evaporative control systems.

- Further development of the database for vehicle exhaust and evaporative emissions at the higher temperatures (greater than 75

°F) likely to be encountered during the summer months in many ozone non-attainment areas, such as the SoCAB. Data for some emission types, such as running evaporative losses, are based on limited data for operation over 75°F.

- Development of region (county)-specific registration and mileage accumulation distributions. Much of this data is available from inspection and maintenance databases, along with more region-specific information on mileage accumulation rates.

The following discussion describes a new type of emission factor model which addresses many of the shortcomings of current versions of both MOBILE4 and EMFAC7.

The key to this model is the use of a modal emissions database to build emission factors on a grams/hr basis, for the facility and area type driving cycle matrix described in Section 3.0. These facility type/area type specific emission factors will be built from a database of vehicle emissions by operating mode. In this case, operating mode will refer to general vehicle operating conditions, such as idle, cruise, acceleration, cold starting, etc. rather than the current limited MOBILE4 definition of cold start, hot start and hot stabilized operation. Combinations of emissions from each of the operating modes will be aggregated to build a driving cycle which approximates vehicle emissions for each vehicle type within a facility type/area type driving cycle combination. The operating mode-specific emission factors will be developed in the Modal Analysis Model, described in Subsection 4.1. The individual emission factors will be assembled into emission factors for specific facility and area types in the Emission Factor Model, described in Subsection 4.2.

4.1 Modal Analysis Model

The Modal Analysis Model will be developed to generate emission factors for several specific driving, or operating, modes. This is in contrast to the current test procedure, the FTP which develops emissions for one driving cycle and adjusts the

emissions for different conditions of speed and temperature. Recent research has shown that certain vehicle operating conditions, such as high loads and accelerations, can produce significantly higher vehicle emissions than normal cruising. The purpose of the Modal Analysis Model will be to quantify vehicle emissions by these specific operating modes.

The design and characteristics of the individual operating modes needed to fully characterize the range of vehicle operations is yet to be completed. However, research towards this need is underway, sponsored by the California Air Resources Board (ARB) and others. For discussion purposes, we estimate that a minimum set of operating modes would include:

- Idle
- Steady state normal (surface street) cruising;
- Steady state high speed (freeway) cruising;
- Moderate acceleration;
- Severe acceleration;
- Deceleration;
- Cold starting; and
- Hot starting.

Previous research by U.S Environmental Protection Agency and others has shown that vehicle emissions over a variety of operating cycles can be reasonably approximated using emissions based on individual operating modes. The output of the Modal Analysis Model would be a set of emission factors describing vehicle emissions by:

- Vehicle Type;
- Operating mode;
- Fuel Type; and

- Ambient Temperature.

Note the lack of vehicle speed as an output of the model. The Modal Analysis Model would express vehicle emissions as a function of operating time rather than distance (grams per hour versus grams per mile). When vehicle emissions are divided into separate operating modes, the effect of vehicle speed can be accounted for in the choice and distribution of the individual operating modes. All of the operating modes listed above are dependent more upon operating time than speed. The exception to this would be steady state cruising. However, while vehicle emissions do change with vehicle speed when expressed on a grams per mile basis, they are relatively constant with vehicle speed when expressed on a grams per hour basis at normal speeds. This trend changes at high speeds such as freeway cruising. For this reason, a separate operating mode for high speed cruising is proposed.

Development of the modal emissions database would obviously require a significant testing effort to include the necessary vehicle types, emission control technology types, fuel types, model years, and emissions levels (normal, high and super emitters). This effort could be mitigated to some degree by developing a driving cycle that includes all of the individual operating modes within it. If emissions were measured on an on-line basis, rather than with discrete bag measurements in the current FTP, then all modes could be measured within one driving cycle. This new simulation could be added to the existing FTP cycle to gather data during the vehicle certification process.

In addition, if the FTP test itself were measured on an on-line basis, the additional information could be used to supplement the added driving cycle. This would provide critical information regarding the variations of the emissions measurements. In turn, this information could be used to help estimate the uncertainty in the emission factor model, an aspect currently lacking from present models.

4.1.1 Evaporative Emissions

The Modal Analysis Model is designed primarily to deal with exhaust and running evaporative vehicle emissions. Stationary vehicle evaporative emissions, such as diurnal, resting and hot soak emissions should be dealt with separately. The current methods used in MOBILE4 does not permit resolution of evaporative emissions by hour of the day. In this motor vehicle source (MV) model, evaporative emissions will be produced from a distinct calculational methodology such as an expanded version of the Coordinating Research Council (CRC) Evaporative Model, EVAP 2.0. EVAP 2.0 was developed by Radian to model vehicle evaporative emissions. The current EVAP model includes diurnal and hot soak emissions and is being modified to include resting evaporative losses.

The current methods in MOBILE or EMFAC are not fully able to account for time and driving cycle effects on diurnal and hot soak emissions. This is due mostly to a lack of available data at the time the models were developed. For example, MOBILE4 and EMFAC7E divide diurnal emissions into three time and driving cycle groups: partial diurnals, full-day diurnals, and multiple-day diurnals. In the development of EVAP 2.0, vehicle driving pattern information has been analyzed to resolve vehicle use characteristics by hour of the day.

Sensitivity analyses of the EVAP 2.0 model has shown many parameters to be significant contributors to evaporative emissions. The analyses also included parameters that were not currently included in the model to help identify areas for further development. The important parameters accounted for in the model include:

- Fuel Reid Vapor Pressure (RVP);
- Ambient temperature;
- Driving pattern;
- Vehicle evaporative emission control technology; and

- Older and/or tampered vehicle emissions.

The EVAP 2.0 model also calculates diurnal and hot soak emissions on an hour-by -hour basis, as opposed to the procedures used in existing models which calculate emissions on a daily basis and assume emissions are evenly spread throughout the day. While this distinction does not affect annual inventories, the EVAP 2.0 model is much more suitable for use in more detailed inventories where emissions are modeled on an hourly basis.

4.1.2 Trip-End Emissions

Many vehicle emissions occur when the vehicle is stationary rather than in running operation. These include diurnal, hot soak and resting evaporative losses as well as cold and hot start exhaust emissions. The current methods used in MOBILE4 do not permit proper spatial allocation of these emissions, since they are calculated on a grams per mile basis and spread over the road network. For regional emission inventories, this is adequate, but as the need for more accurate emission estimates increases, it will be difficult to achieve the proper spatial resolution with the current method.

This MV model will permit proper spatial allocation of both exhaust and evaporative emission since they will each be calculated separately. In this way, it will be possible to allocate the emissions closer to where they occur. In addition, by separating emissions into individual operating modes, it will be possible to construct operating cycles specific to certain areas, such as freeway entrance and exit ramps. This should further improve the spatial resolution capabilities of the model.

4.1.3 Alternative Fuels

The potential growth in the number of automotive fuels presents a significant logistical problem for a future motor vehicle source model. The problems that alternative fuel use presents include:

- Determining the emission characteristics of vehicles operating on different fuels;
- Quantifying the use of different fuels by vehicle type;
- Spatially resolving the emissions from alternative fuel use; and
- Dealing with the variable emissions of flexible-fuelled vehicles.

If the fuels under consideration had enough similarities, it might be possible to group fuel by their emission characteristics. However, the significant differences in emission characteristics of the fuels currently being considered require the development of individual databases for each fuel.

In this MV model, modal exhaust and evaporative emissions will be determined by fuel type for each affected vehicle type. It is proposed that the MV model develop emission factors, rather than corrections to the existing gasoline-based emission factors. One advantage if the fuels are dealt with separately is the capability to add new data if more fuel types become available. The Modal Analysis Model will output emission factors by fuel type for each operating mode.

The difficulty of dealing with flexible-fueled vehicles presents a unique problem, since their emission characteristics vary with the fuel being used. At this time, it does not appear that flexible-fueled vehicles operating on a wide range of fuels will be common enough to warrant special treatment. Most likely, vehicles with flexible fuel capability will be operated primarily on specific types of fuel, enabling the use of specific emission factors. Although survey data should be gathered, the time spent operating on

non-standard fuel blends may be small enough to be treated through small adjustments to the standard fuel emission factors.

4.2 Emission Factor Model

The Emission Factor Model takes the individual operating mode emission factors from the Modal Analysis Model and combines them to form driving cycle emission factors specific to the elements of the Driving Cycle Matrix (see Table 3-1). Separate emission factors will be constructed to reflect peak (congested) and off-peak (uncongested) travel.

The driving cycle will be a composite emission factor that reflects the percentage of time the fleet spends in each of the individual operating modes. To build a composite emission factor for a specific facility type and area type, survey data are needed to determine the amount of time spent in each of the individual operating modes. This time distribution is then used to develop a single facility type/area type emission factor from the composite of the individual emission factors. The time distribution concept is demonstrated in a hypothetical example shown in Figure 4-1. The example shows two distributions, both for an urban (area type) freeway (facility type), but for on-peak and off-peak travel.

Operating mode time distributions will be developed for each facility type, area type and congestion level (on-peak or off-peak) through survey data. It will be possible to embed default time distribution values into the model for applications where region-specific data are not available. If other data are available, then the user can have the opportunity to input new operating mode distributions for specific facility and area types.

One immediate advantage to the proposed system is the ability to use region-specific information regarding operating mode distributions. Additionally, it is

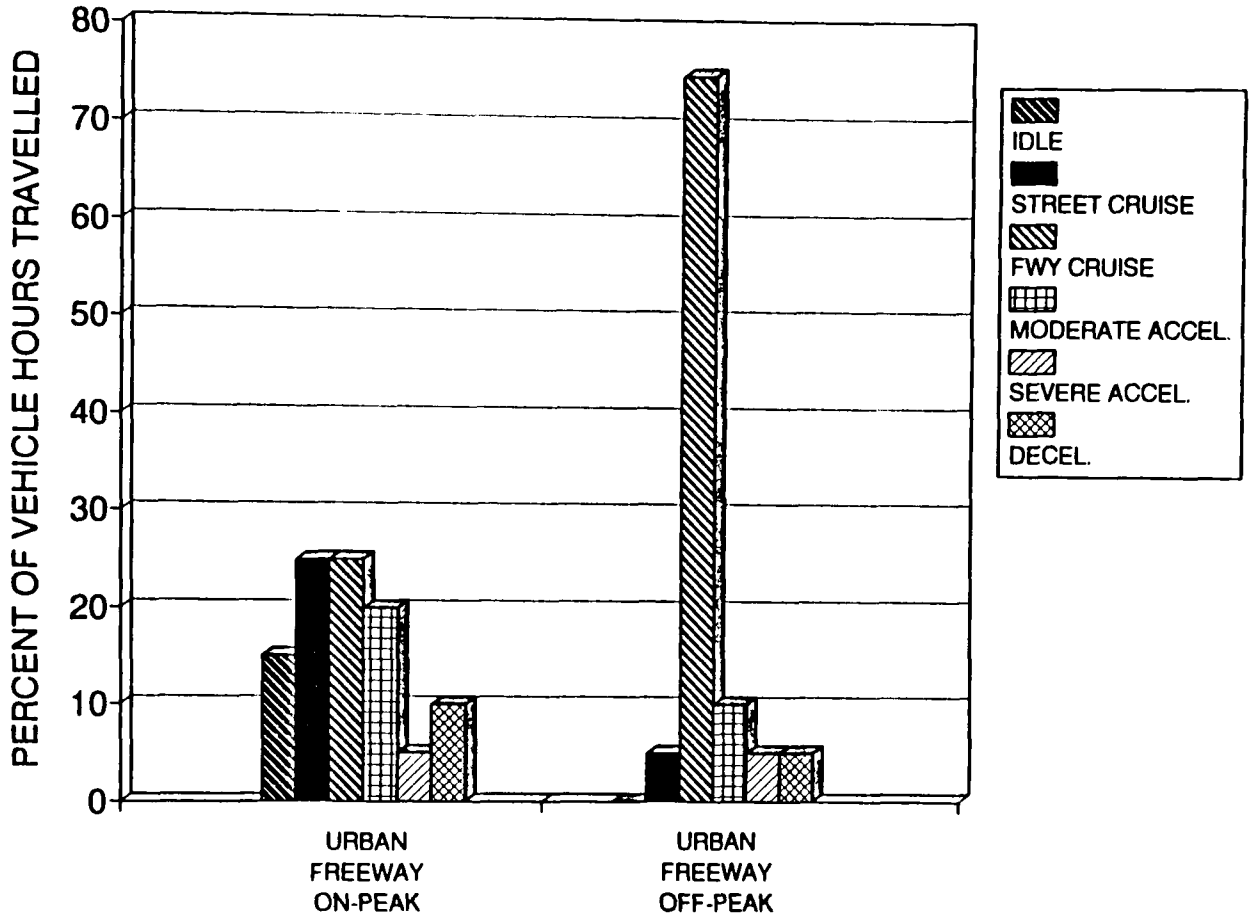

Figure 4-1. Hypothetical Driving Cycles for Urban Freeway-Operating Mode Distribution.

also possible to easily create additional facility or area types with unique operating mode distributions. In this way, the model can be truly customized for local applications.

Once the composite facility type/area type driving cycle emission factors are calculated, the emission factors are combined with the vehicle activity data developed from the transportation models for each link and node. The activity data will include:

- Total vehicle hours traveled (VHT) on a link;
- Distribution of VHT by vehicle type and fuel for each link;
- Number of cold starts, hot starts for each node;
- Number of park hours for each node (diurnal and hot soak emissions);

The product of the emission factors and the vehicle activity data will be exhaust and evaporative emission estimates by individual link and node for each hour of the day. The development of emission estimates is described in more detail in Section 5.0.

5.0 DEVELOPMENT OF EMISSION ESTIMATES

Travel demand estimates on a link-specific basis need to be combined with corresponding emission factors to develop emission estimates. The methodology that is used to perform these calculations should be able to handle regional variations in temperature on an hourly basis. In addition, it is desirable to be able to grid and speciate the resulting emission estimates for use in photochemical models. Currently, the only software available to calculate link-specific emission estimates and to grid and speciate those values is the Direct Impact Travel Model (DTIM) developed cooperatively by the California Air Resources Board (ARB) and the California Department of Transportation (CALTRANS). DTIM reads CALTRANS formal trip assignment and network description files and files of emission rates generated by EMFAC7. DTIM uses these travel demand estimates and emission factors to develop gridded emission estimates. DTIM permits travel demand estimates represented on the assignment file to be allocated to any hour of the day with a corresponding temperature. The user can also provided gridded temperature values on an hourly basis. The CALTRANS trip assignment program and its output file allow trips to be stratified by time of day or trip purpose, each with separate emission factors. DTIM resolves both link and zonal emission estimates into user-specified grid cells. However, DTIM is written in FORTRAN and is difficult to use. The Radian motor vehicle model will use a more user-friendly model to compute link-specific emission estimates that is based on the use of fourth generation software (i.e., SAS® and ARC/INFO®).

Radian's motor vehicle source (MV) model (see Figure 2-1) will accept as input the ARC/INFO® transportation network configuration from the TMS (for urbanized areas) and the off-network transportation system (for rural areas) as described in Section 3.0. These coverages will then be merged into a single coverage of links and nodes (including TAZ centroid nodes) for the entire region (i.e., both on-network and off-network domains). The links that comprise these coverages will contain the hourly vehicle hours traveled (VHT) (for use with the grams/hr emission factors) and an

identifier which matches a given link with a driving cycle (from the driving cycle matrix, based upon the facility type/area type combination that best characterizes a given link). TAZ nodes will contain relevant trip end data.

A coverage of gridded temperatures will be developed based upon the use of observed values or the output of a meteorological model, and the temperature will be added to each link/TAZ node. A separate coverage will be maintained for each hour of the day.

These coverages will be converted into SAS® data sets and passed through a temporal and spatial adjustment processor which will allow the modeler to modify temporal profiles or link-specific vehicle hours for a user-defined area (useful for sensitivity analyses and forecasting purposes).

A link-specific age-composited emission factor, for each vehicle class, will be obtained from the emission factors that have been developed for each driving cycle. An emission factor look-up table based upon temperature will be developed for evaporative, cold start/hot start and diurnal emissions. Each link will contain the vehicle mix (i.e., fleet mix), which is obtained from its respective facility type/area type classification. The emission factor for that link/node, for each vehicle class, will be obtained from the look-up table, fleet composited, and added to the file.

Emission estimates for each link/node will be computed in SAS® by multiplying the fleet composited emission factor by the VHT trip end activity data (assigned to each TAZ node as described earlier). This computation will be performed for each link and TAZ node, for each hour of the day. The SAS® data set containing the link/nodes and emission estimates will be converted back into ARC/INFO®. A series of hourly coverages, which now includes the appropriate emission estimates, will be gridded in ARC/INFO® according to a user-defined grid structure (uniform grids, variable grids, nested grids, etc.).

The gridded, hourly coverages will be converted back into SAS® and speciated according to user-specified speciation profiles. The speciated VOC emissions can be used to generate emission reports or combined into the user-defined VOC-species groupings required by the chemical mechanism in a desired photochemical model.

6.0 DATA INPUT REQUIREMENTS

The following provides a list of the types of data inputs that will be required to run Radian's new motor vehicle model:

- Socioeconomic/Demographic data;
- Origin/Destination travel surveys;
- Origin/Destination trip tables, by hour of the day;
- Traffic count data;
- Transportation system roadway characteristics;
- Tiger/Line data;
- Fuel sales;
- Gridded temperatures for region under analysis;
- Vehicle mode test data;
- Region-specific vehicle data (e.g., registration distributions, I/M programs, etc.);
- Engine maps;
- Driving cycle matrix (by facility type and area type);
- Grid definition; and
- Speciation profiles.

The resources required to gather these data will be substantially greater than those needed to use current procedures. The cost of obtaining the detailed origin -- destination travel survey information necessary to develop the travel demand estimates for Radian's motor vehicle source model will be significant. However, several options for minimizing the amount of resources needed to conduct these surveys were presented in Section 3.0. In addition, the mode test data needed to develop the driving cycle matrix and associated emission factors will also be costly. On the other hand, motor vehicles are the most important source category in most urban areas and a strong argument can be made that more resources should be devoted to improving the methodology used to characterize motor vehicle emission estimates.

7.0 MOTOR VEHICLE SOURCE MODEL VALIDATION PROCEDURES

One of the most important elements of model development is the procedures that will be used to verify the resulting emission estimates and travel demand data used to drive the model. The following discussions describe different techniques that will be used to verify Radian Corporation's motor vehicle source (MV) model.

7.1 Tunnel Studies

Perhaps the best known tunnel study is the 1987 Van Nuys tunnel study conducted by Southwest Research Institute for the Coordinating Research Council (CRC) as part of the Southern California Air Quality Study (SCAQS). In this work, carbon monoxide (CO), volatile organic compounds (VOC) and nitrogen oxide (NO_X) concentrations were measured by bag sampling of the air in the tunnel and at the tunnel entrance and exit. These measurements were used, along with measurements of air flow rate into the tunnel and examination of the vehicle flow characteristics, to determine overall emission rates for the vehicle population traveling through the tunnel. Emission rates were compared with those predicted by EMFAC7. VOC and CO emissions were considerably higher than those predicted by EMFAC7, while NO_X emission rates compared favorably. Additional tunnel studies could be conducted to verify emission estimates generated by the new MV model.

7.2 Remote Sensing

Remote sensing instrumentation has recently been developed to monitor CO levels and has been used to identify CO super emitters. This type of equipment will soon be expanded to remotely monitor VOC emissions from vehicles. These measurements could be used to verify emission rates for in-service vehicles operating on links that have been categorized as following a particular driving cycle and then compared to motor vehicle model emission rates.

7.3 Source Apportionment

Researchers are developing source apportionment techniques to develop emission estimates. These techniques could be applied in areas where emissions are dominated by vehicles, and the resulting emission estimates could be compared to those generated using the MV model. This technique might be especially useful in verifying vehicle speciation profiles that will be incorporated into the MV model.

7.4 Fuel Sales

Gridded vehicle fuel (e.g., gasoline) sales could be obtained for a particular region and using average vehicle fuel economy (miles per gallon), vehicle miles traveled (VMT) estimates could be generated. Average speed estimates could be used to convert VMT to vehicle hours traveled (VHT) and emission estimates could be computed. These gridded emission estimates could be overlaid on gridded emission estimates produced by the MV model, using GIS techniques, and used to check the reasonableness of model predictions.

7.5 Traffic Count Programs

Traffic count programs could be established to verify the traffic volumes predicted by the TMS on various links in the driving cycle matrix. Many researchers consider traffic counters the equivalent of ambient air quality monitors. Such traffic count programs could also be used to verify the temporal profiles used in the driving cycle matrix and hourly trip rates used in the trip assignment model of the TMS. In addition, information regarding weekday/weekend travel pattern variations and seasonal changes could also be obtained from traffic count programs and used to verify profiles and adjustment factors included in the MV model.

7.6 Satellite Imagery

Satellite imagery, in the future, might be used to check traffic volumes on selected links and compared to those generated by the TMS. It might even be possible to use these techniques to derive estimates of vehicle distributions and check those against profiles used in the MV model.

APPENDIX E

CONCEPTUAL DESIGN OF A NEW HIGHWAY
VEHICLE EMISSIONS ESTIMATION METHODOLOGY

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1. INTRODUCTION

1.1 Understanding the Problem

As the stringency of the federal motor vehicle emissions control program has increased, the relationship between the standards vehicles are required to meet and the actual performance of vehicles in customer service is becoming more of an issue. Based on the official certification test results for cars built during the last decade, exhaust emissions of hydrocarbons (HC) and carbon monoxide (CO) should have been reduced by over 90% and oxides of nitrogen (NOx) emissions by over 75%, evaporative hydrocarbon emissions should have been reduced by over 90%, and crankcase emissions should have been eliminated. Despite these findings, numerous communities across the country have failed to attain the National Ambient Air Quality Standards (NAAQS) for either CO or ozone. Concerns about the contradiction between laboratory measurements and on-road performance have been further enhanced by "tunnel" studies which indicate that current estimates of motor vehicle emissions produced by EPA and the California Air Resources Board (ARB) seriously underestimate the levels of HC and CO being emitted under in-use conditions. There are many reasons for the problems with motor vehicle emission estimates. Some are well understood and steps are being taken to resolve them, others are just beginning to be explored.

Lack of proper maintenance in customer service is known to be a major factor that the motor vehicle inspection/maintenance (I/M) programs are attempting to address. Previous studies by Sierra Research have shown that emissions could be reduced by over 50% if all vehicles were properly maintained. Current programs, however, are achieving limited benefits. For example, Sierra's evaluation of the California Smog Check program in 1987 showed that HC and CO reductions were only in the range of 10%. Based on the use of a computer model developed by Sierra, the latest enhancements to the California Smog Check program are projected to yield net emission reductions (for vehicles subject to the program) of only 20-25% for HC and CO. Assuming that these estimates are not unrepresentative of programs operating in the rest of the country, substantial program enhancements are necessary to improve the quality of maintenance being received by vehicles in customer service.

Inadequate control of evaporative emissions is a problem that has been recognized more recently and is soon to be addressed through the use of lower volatility gasoline and revised evaporative emissions test procedures. Under the evaporative emission test procedures that have been used for the last twenty years, there has been no requirement to measure or control emissions that occur during multiple days of inactivity, during extremely high temperatures, or during periods of time when the engine is running (running losses). The new evaporative test procedures will force the redesign of evaporative control systems to deal more effectively with the full range of conditions that occur in

customer service; however, cars already in customer service will be unaffected. Data for such vehicles are needed to accurately estimate the emissions from the motor vehicle fleet.

A problem similar to that with the evaporative emissions test procedure also exists with the basic test procedure used to measure exhaust emissions. Under the official test procedure, exhaust emissions are measured during stop and go driving using a driving cycle that was developed about twenty years ago. By its very design, the "LA4" driving cycle was intended to represent a typical commute trip, by a typical driver. As a result, the cycle does not reflect the full range of vehicle operation that is known to occur. One of the most obvious weaknesses of the cycle is that it contains very modest acceleration rates. This has enabled vehicle manufacturers to disregard emissions during higher rates of acceleration. Given the stringency of the current emission standards, there can be a 100-fold difference between the level of emissions control that must be achieved during the official test procedure and the level of emissions that occurs when no emissions control is required. Another perhaps less obvious problem with the current test procedure is that it is based on the assumption that only two "cold starts" occur each day and about three other engine starts can be represented by the emissions from a vehicle that was thoroughly warmed up and then shut off for exactly ten minutes. Data currently being obtained by Sierra under contracts with EPA and ARB indicate that this is a very bad assumption. Based on surveys being conducted in the Sacramento area, it appears that there may be substantially more engine starts per day that previously assumed and many of those starts may be with an engine that isn't fully warmed-up.

For reasons discussed above, and for similar reasons, there is substantial uncertainty regarding the current estimates and forecasts of emissions of motor vehicles in customer service. Further work is required to:

- better characterize vehicle operation in customer service;
- revise emission estimates to reflect the full range of vehicle operation observed in customer service;
- analyze the feasibility of improving the identification and correction of maintenance-related problems by using more sophisticated I/M concepts;
- develop estimates of evaporative emissions from vehicles in customer service using more representative test procedures; and
- revise the current approach used to estimate mobile source emissions to include the information improvements outlined above.

1.2 Project Objectives

The RFP specifies that the goal of the effort is to "develop a highway vehicle emissions estimation conceptual design that could be implemented nationally within 5-10 years." The model must be capable of tracking the emissions produced by all expected vehicles, technologies and fuels. It must also be capable of estimating the benefits of all potential emission control strategies (e.g., I/M program design changes and a variety of transportation control measures). In short, the proposed design must not only replace the existing methodology used by states and local communities to develop emission inventory estimates, but also expand the range of tools available to develop these estimates (EPA does not currently offer a system to estimate the benefits of transportation control measures).

Emission inventory estimates require information on vehicle activity as well as the rate at which pollutants are emitted. Therefore, the proposed system must address not only the approach used to develop emission factor estimates, as discussed above, but also the methodology used to develop vehicle activity estimates. At present, communities are pretty much left to their own devices when it comes to developing estimates of local travel levels. Recently, EPA and the U.S. Department of Transportation (DOT) have prepared guidance on the methods that should be used in developing local estimates of travel that are incorporated in emission inventory estimates submitted in response to the 1990 Clean Air Act Amendments.

It appears, however, that little research is being devoted to developing new tools that improve the accuracy of local travel patterns. It is unclear how emission inventory estimates can be improved unless there are similar improvements in local travel estimates. For this reason, the proposed methodology must identify areas of inadequacy in the current models that are used to develop local estimates of vehicle activity and make recommendations for improvements.

1.3 Report Organization

Immediately following this introduction is a discussion of the proposed model structure in Section 2. It includes a description of each of the modules contained in the model and available data sources that can be used to support their development. Section 3 presents a summary of the cost of developing this model compared with current procedures. Section 4 discusses methods that could be used to validate the results of the proposed model.

###

2. MODEL DESCRIPTION

2.1 Model Logic

The following principles/assumptions guided the development of the proposed motor vehicle emissions estimation methodology:

- Driving patterns in each urban community are believed to be unique.

- The current driving cycle is not representative of driving patterns in nonattainment communities. More importantly, correction factors cannot be used to adjust any driving cycle to accurately represent the effects of local driving patterns on motor vehicle emissions.

- Emissions are not "nearly constant for varied speeds over time."

- Accurate estimates of total urban emissions are insufficient, they must also be temporally and spatially resolved.

- Limited changes in the accuracy of transportation planning models are possible. Nevertheless, it is believed that estimates of heavy-duty vehicle operation can and will be added to most models. It is also expected that the accuracy of zone-specific travel estimates will be substantially improved.

- Uniform goals for accuracy will be established for both travel and emission factor estimates at the beginning of the project. A system will be established to track the accuracy of both estimates throughout the model development process.

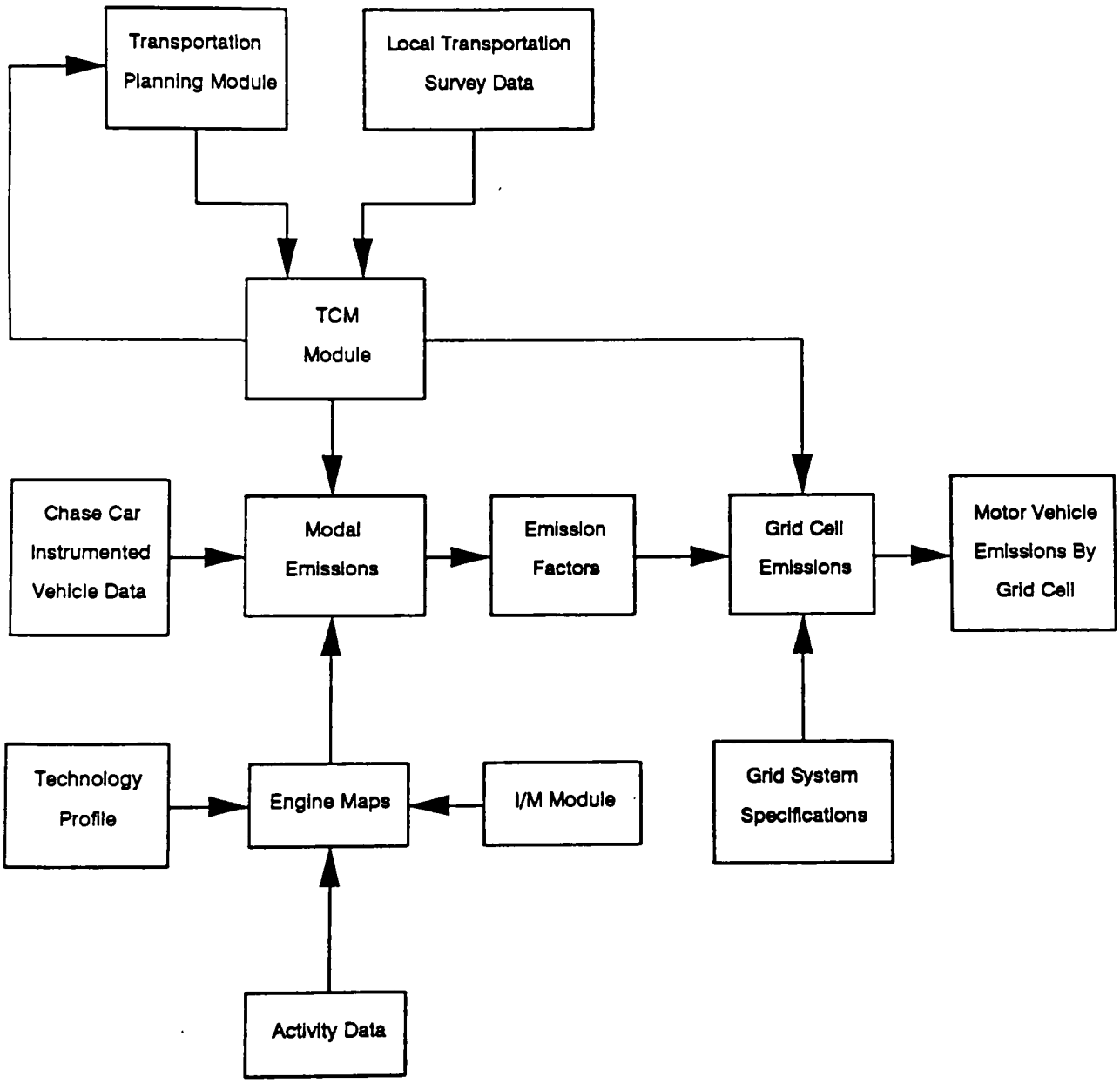
- Local transportation surveys will collect travel information that can be used to aid the development of motor vehicle emission estimates.

- Improvements in computer technology will continue, resulting in faster processing power and greater data storage capacity.

An overview diagram of the proposed motor vehicle emission methodology is contained in Figure 2-1. It shows an approach to estimating motor vehicle emissions that is fundamentally different from the one currently employed by either EPA or ARB. First and foremost, it scraps the use of a single drive cycle with correction factors to account for the effects

Figure 2-1

Proposed Motor Vehicle Emission Methodology



of local driving conditions on emissions estimates. Instead, it is proposed that separate emission factor estimates be constructed for each link on unique trip routes. This can be accomplished by modifying transportation planning models to supply information on the trip length, mix of roads (i.e., facility types) and congestion encountered on routes between each origin and destination zone (OD pair). It is also proposed that similar information be developed for the travel that occurs within each traffic analysis zone. As will be discussed later, this information can be developed either through use of local surveys or the improvement of transportation models to better account for this category of travel.

The heart of the proposed methodology is a modal emissions model. It will combine route-specific travel information, including the length of time between starts by trip type and hour of the day, with (1) a distilled version of the data collected in the ongoing EPA and ARB drive cycle studies on operating conditions (e.g., idle time, speeds and accelerations, etc.) encountered on similar roads (i.e., grade as well as road type) under similar congestion levels and (2) engine maps that characterize emissions as a function of speed and load for a representative set of vehicles. The output of this calculation is a specific emission factor for each link encountered on each trip.

The distribution of engine maps used to represent the mix of vehicles operating within an area is governed by a series of relatively familiar modules. The profile of technologies employed by model year is governed by the technology module. It incorporates a summary of the mix of fuel and emission control technologies manufactured in previous vehicle type/model year groups along with a projection of the mix of technologies that will be employed within each vehicle category in future model years. The activity module specifies the default distribution of vehicle categories by model year and the engine maps needed to represent the baseline mechanical distribution of vehicles on the road. The I/M module quantifies the effect of the local I/M program on the mechanical condition of the vehicle fleet and in turn, the effect of the I/M program on vehicle emissions.

The outputs of the transportation planning module and local trip surveys are input to the transportation control measure (TCM) module. That module evaluates the effects of alternative TCMs on the travel-related determinants of vehicle emissions: the relationship between vehicle trips and person trips, trip length and congestion levels. It provides a feedback loop to the transportation planning model to reevaluate the level of travel produced when measures substantially alter baseline travel behavior.

The transportation planning module provides two separate outputs. The first is information on the trip type (which in fact may come from a travel survey), trip length, mix of roads (i.e., facility types) and congestion encountered on routes between each origin and destination zone and within each traffic analysis zone (TAZ). The first set of outputs is input to the modal emissions model. The second set of outputs is the actual number of vehicle trips between zones and within zones; this is input into the grid cell emissions module.

The grid cell emissions module integrates data on the characteristics of the road network and TAZs with link-specific emission factor estimates for each OD pair and the number of trips between each OD pair. A similar computation is used to estimate the emissions within each TAZ. The grid cell emission module aggregates the link and TAZ emission estimates into the grid cells specified by the user.

A complex set of controls is required to operate the proposed modeling system. Not shown, but implicit in the system, is a set of preprocessing steps that are needed to translate local information (e.g., travel survey, node coordinates, etc.) into a format that is compatible with the proposed modeling structure. A more substantial effort is required to organize the information collected in the ongoing chase car/instrumented vehicle surveys into a range of common facility/congestion and grade specific travel profiles.

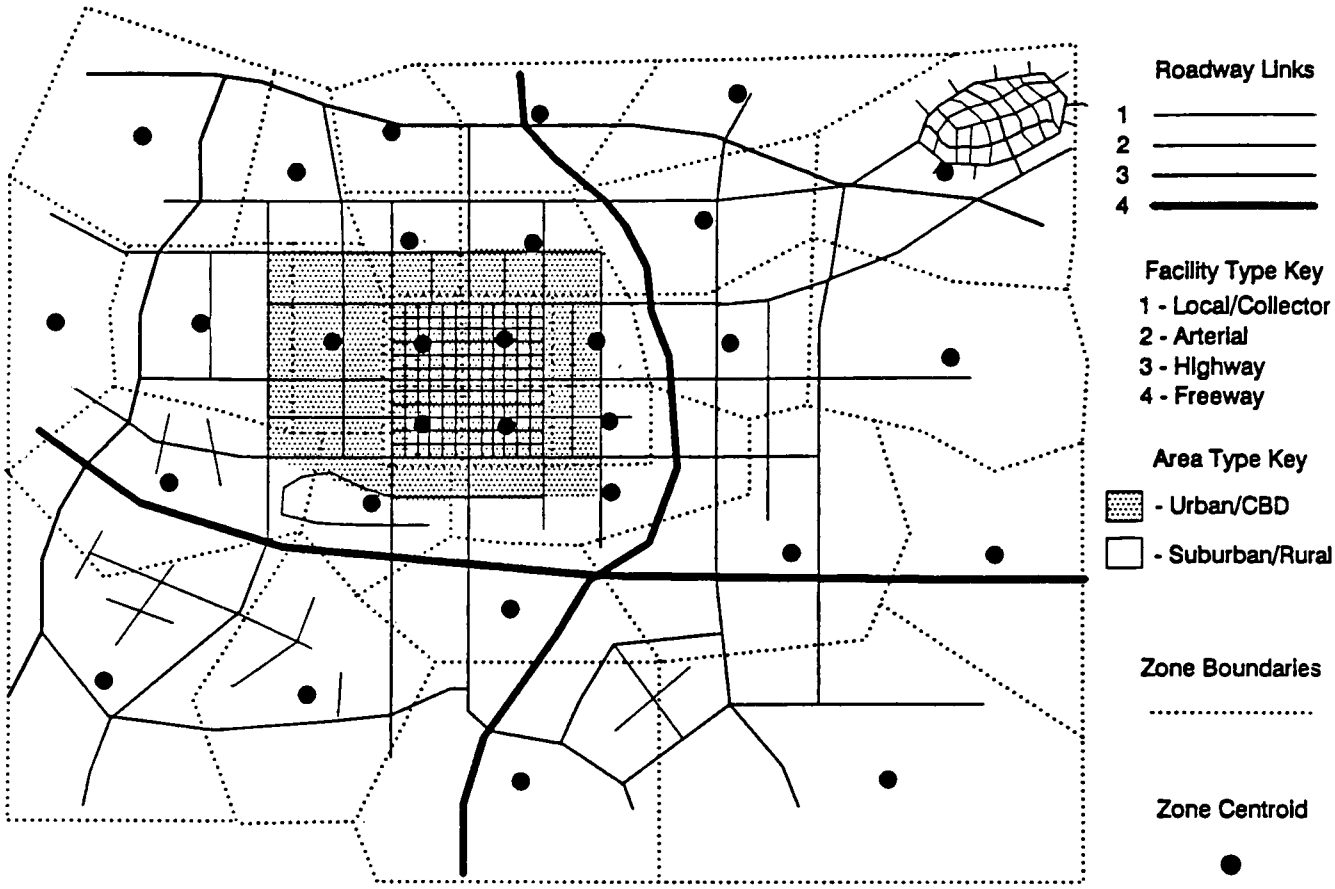
The decision to use this approach was largely motivated by the requirement to accurately resolve emissions estimates, both temporally and spatially. Motor vehicle emissions are disproportionately high during cold start operation and under high acceleration rates. This means that emissions are high during the time before catalyst light-off (and to a lessor extent, before the engine fully warms up) and on certain types of roads where high levels of acceleration occur. Extremely high levels of emissions occur when hard acceleration rates are experienced before the catalyst lights-off. The emissions from these events cannot be spatially resolved with any appreciable accuracy using average values.

2.2 Module Descriptions

Transportation Planning Module - This module requires several categories of outputs from transportation planning models. Figure 2-2 provides an illustration of the zone/node structure employed in transportation planning models. It is presented to help the reader visualize the different categories of information discussed below. The first category covers interzonal travel and includes the trip generation matrix (i.e., number of trips between origin and destination zones) for peak periods of operation; the distribution of trip types (e.g., home-based work, home-based other, etc.) for each OD pair by period of operation; and the specific links included in a representative trip path between OD pairs. The network description must include a specification not only of distance between node points, but the grade as well. With the above information, it is possible to compute the trip length and the fraction of the trip that occurs on each link and facility type. As discussed earlier, it is assumed that most transportation planning models will be upgraded, within the time horizon envisioned for this effort, to include both commercial vehicle operation and through traffic.

Figure 2-2

Illustration of Zone/Node Concept Used In Transportation Demand Modeling



The second category of information addresses intrazonal travel. At present, this is the number of trips estimated for equal OD pair zones (e.g., 1-1, 2-2, etc.) in the trip generation matrix. Conversations with transportation planners, university researchers and consultants in the field all agree, however, that these estimates are quite weak. No information on the intrazonal road structure is included in the road network, and trip lengths within the zone are frequently approximated on the basis of the diameter of the zone. These simplifying assumptions are used despite the documented shift in shopping trips and recreational travel toward local/regional shopping and recreation centers. As discussed later, one of the assumptions driving the development of this approach is that money will become available from several different sources to improve the state of the art in estimating the level of travel within zones. It is also assumed that because of this research, travel estimates on a par with those developed for interzonal travel will become available for use in the development of motor vehicle emission inventories.

Several of the outputs specified above are not routinely produced by existing models. For example, it is possible to prepare code that

tracks the links in assigned trips between OD pairs; however, it is not a routine product. Similarly, information on grade is not routinely coded for the road network. It should also be obvious that most of the suggested improvements noted above do not currently exist.

Transportation Surveys - Surveys are infrequently conducted by local transportation planning agencies to quantify the travel behavior of a representative sample of the population. The data collected in the surveys are used to specify many of the travel profiles that characterize behavior in the transportation planning models. These profiles (e.g., average commute trip length, average vehicle occupancy, etc.) are also needed to support the evaluation of TCMs.

The travel surveys can be expanded to collect information that can be used to either support the development of the intrazonal travel estimates discussed above or to provide the basis for developing exogenous estimates of the distribution of trips and trip lengths occurring within each of the TAZs. The surveys can also be used to estimate the fraction of hot and cold starts that occur within local communities. This can be accomplished through the use of home interviews or diaries that track the time of each trip in a typical day. By analyzing the time between starts and stops, it is possible to determine the condition of the engine and catalyst at the start of each trip. The alternative to this information is the use of defaults that will be developed from the planned instrumented vehicle surveys.

It should also be noted that the transportation control measure module will require a substantial amount of information about the cost of local travel (e.g., cost per gallon of fuel, average out-of-pocket commute trip expense, etc.). Information on the mix of vehicles operating on typical roadways will be required by both the transportation planning models (to evaluate the benefits of goods movement) as well as the modal emissions model to correctly specify the mix of vehicles operating on facility types (heavy-duty trucks are much more prevalent on freeways than collectors). This information will not be supplied by either the transportation planning model or the travel surveys discussed above. This information is developed from a variety of sources and related but separate surveys.

Transportation Control Measures - A wide variety of TCMs are currently being evaluated as nonattainment areas search for alternative control strategies to reach attainment. Table 2-1 provides a summary of the travel characteristics needed by a TCM analysis model developed for use by air pollution control districts in California. That model, developed by Sierra and its subcontractor JHK, quantifies the effects of 25 separate TCMs on the parameters that current emission factor models use to determine emissions (i.e., trips, VMT and speed). The proposed methodology will not require information on speed, but will require information on trips and trip length. Therefore, it is assumed that the basic travel parameters outlined in Table 2-1 should be representative of the information that will be needed to support the quantification of TCM benefits.

Table 2-1

BASELINE TRAVEL CHARACTERISTICS	
General	
Total person trips	1
Total commute person trips	1
Total commute vehicle trips	1
Total non–commute vehicle trips	1
Total peak period VMT	1
Total off–peak period VMT	1
Drive–alone share of commute person–trips	79.7%
Percent of all trips in peak period	39.6%
Percent of all trips that are commute trips	33.8%
Percent of all trips that are non–commute trips	66.2%
Percent of commute trips in peak period	60.8%
Percent of non–commute trips in peak period	28.8%
Percent of peak trips that are commute trips	51.9%
Percent of off–peak trips that are commute trips	21.9%
Average commute trip length	10.7
Average non–commute trip length	6.0
TCM Specific	
Demand Management	
Average daily commute out–of–pocket costs per vehicle	$5.00
Average number of telecommuters per day	0.0
Transit Improvements:	
Percent of all trips that are transit	1.0%
Commute trip share of transit	52.0%
Total transit vehicle miles	0
Bicycle:	
Percent of commute trips less than 6 miles	25.0%
Percent of non–commute trips less than 5 miles	25.0%
Pricing:	
Average cost of gas per gallon	$1.44
Average cost per mile to drive	$0.300
Average commute out–of–pocket costs per vehicle per trip	$3.00
Average non–commute out–of–pocket costs per vehicle per trip	$1.00
Freeway Management/Goods Movement	
Percent of VMT on freeways	55.8%
Average trip length for trucks	10.7

Current TCM models compute the effect of individual TCMs on aggregate levels of travel. The model structure outlined in Figure 2-1 provides for a feedback loop between the TCM module and the transportation planning model. This feedback can be used to evaluate the effects of significant changes in trip generation rates (as will be discussed in Section 4, on the order of 5 percent or more). This approach also allows for a more sophisticated appraisal of the effects of alternative TCMs (e.g., land use controls which shorten future trip lengths) on future travel patterns.

Facility Type Travel Profiles - Ongoing EPA and ARB drive cycle studies are collecting information on vehicle operating conditions (e.g., idle time, grade, speed and acceleration, etc.) using two primary data collection methods: chase cars which follow traffic over representative road routes, and instrumented vehicles which record operating data from a representative set of vehicles. These studies will be conducted in a minimum of four communities across the country. The data collected will be used to develop a "representative" driving cycle by EPA that could be used to certify new vehicles. ARB plans to develop three separate driving cycles that are representative of the travel that occurs during each of the peak operating conditions of the day (i.e., a.m. peak, p.m. peak and off-peak). These cycles will be used to improve the accuracy of existing emission inventory estimates.

The data collected in the chase car studies will provide the basis to quantify typical driving profiles that occur on different categories of roads (i.e., facility types) as a function of congestion (time of day) and grade. Similarly, the data collected in the instrumented vehicle study will provide the information needed to quantify the distribution of short trips (i.e., less than a tenth of a mile) that frequently occur off public roads in shopping centers and driveways as well as the soak time between trips by trip type. The results of these analyses can be organized into data files that quantify the driving profiles of vehicles over all possible roads within urban nonattainment areas.

Modal Emissions - Both ARB and EPA are supporting the development of a modal emission model entitled "Vehicle Simulation-Emissions" (VEHSIME). It determines the power demands required for a specific engine/vehicle combination to achieve instantaneous speed and acceleration rates on a second-by-second basis for any specified time-speed trace. Based on the engine-transmission combination, second-by-second power values are translated to engine speed load values. Fuel consumption and emissions are interpolated from a steady-state map of emissions and fuel economy for the full range of the engine.

As shown in Figure 2-1, the proposed modal emissions model requires three primary inputs: travel profile of the trip of interest; the mix of possible time/speed profiles that can be encountered on links within the route of interest; and a set of engine maps that are representative of vehicles operating within the community of interest. A critical input also required is the average soak time between trips.

The travel profile must specify the length and grade of each node that makes up a trip route. The facility type travel profiles must specify the time speed trace on a second-by-second basis for individual roads as

a function of congestion and grade. The engine maps require measurements of fuel consumption and emissions for specific engine speed and load points.

Even after the current work of adding a cold start algorithm and increasing the number of available engine maps is completed, a substantial amount of work to be required to allow the model to operate in the manner envisioned in this module. Software would be required to integrate trip requirements with the available facility profiles and the soak time. Multiple runs of the model would be required to integrate the effects of alternative engine maps representing different model year groups and technologies. Software would also need to be developed to quantify the link specific emission factors.

Technology Profile - The technology profile specifies the mix of fuel types (gasoline, Diesel, etc.), fuel delivery systems (e.g., multipoint versus throttle-body fuel injection) and emission control technologies (e.g., three-way closed loop versus oxidation catalysts) manufactured in previous vehicle type/model year groups. It also provides a forecast of the mix of technologies that will make up future vehicle category/model year groups. Current emission factor models track up to five separate technology categories for the 25 model years that make up the vehicle fleet in a single calendar year. As discussed below in the I/M module, each technology group has multiple emission regimes. The disaggregation of the vehicle fleet into more than 250 subcategories of emission performance has significant implications for the information requirements of the engine map module.

Engine Maps - Engine maps consist of formatted data files that contain emissions and fuel consumption rates over a range of engine speeds and loads. At each speed/load point, supplemental information regarding throttle angle (in degrees) and manifold vacuum values (in inches Hg) may also be included. At present, VEHSIME can only accept engine maps with up to 20 different speeds and 20 different loads at each speed. It is possible, however, to expand the size of the matrix to cover a greater number of points over the range of potential engine operation.

I/M Program Benefits - I/M programs are designed to reduce the level of pollutants emitted by vehicles operating under in-use conditions. Differences in program designs can have a significant impact on their effectiveness in reducing emissions. For example, the date at which an I/M program is first implemented, or the date when significant program changes take effect, has implications for the benefits of the program. EPA and ARB I/M models currently segregate the vehicle population into different emission regimes (e.g., normals, moderates, highs, supers, etc.). The California I/M model CALIMFAC simulates deterioration by modeling the migration of vehicles from one regime to another with increasing mileage. Emission factors for specific technology/model year groups are developed from test data representing the mix of emission regimes. The benefits of I/M are quantified by altering the baseline mix of emission regimes.

The proposed methodology would require the development of engine maps of fuel consumption and emissions for a mix of vehicles with implanted defects designed to simulate the range of possible emission regimes for

each model year and technology group subject to an I/M program. Baseline fleet average emissions would be based on a mix of engine maps representing not only the appropriate model year technology groups which make up the vehicle fleet, but also the range of defects found in that fleet. The benefits of I/M would be quantified by altering the mix of defects found in that fleet.

Activity Profile - The activity profile specifies the default distribution of vehicle categories and model year registrations within each vehicle category. This information must be combined with the distribution of technologies that make up each model year/vehicle category to specify the mix of engine maps needed to represent the in-use vehicle fleet. Information on the registration status of vehicles is also tracked to support the quantification of I/M program benefits (unregistered vehicles are not likely to be inspected).

The level of detail included in this profile could be expanded to provide default estimates of the mix of vehicles operating on different classes of roads at different times of day. Current inventories assume that the mix of registered vehicles is uniformly operated over the entire road network. Data collected in ARB's San Joaquin Valley Air Quality Study have shown that there are substantial variations in the mix of vehicles operated on individual road categories.

Emission Factors - A specific emission rate for each link in a specified trip route is required. It is unclear how the effects of ambient temperature would be accounted for in the proposed modeling structure. One method would be to adjust the cold start profile used in the modal emissions model to account for the effects of alternative ambient temperatures on catalyst and engine warm-up. Another approach would be to adjust the emission estimates produced by the modal model. If the latter approach were selected, the emission factor module would be the appropriate location for the correction factor to be applied.

Grid System Specifications - This set of inputs defines the boundaries of cells within the modeling domain. Zonal (TAZ) boundaries must also be identified so that intrazonal emission estimates can be properly allocated to grid cells. It is expected that a standardized coordinate system would be used to define grid cell and zone boundaries. A GIS (Geographic Information System) could be used to map irregularly shaped TAZs into rectangular grid cells.

Grid Cell Emissions - Trip route and link-specific emission factors are combined with trip volume estimates from the TCM module to estimate link-specific pollutant emissions for each trip route for OD pairs (interzonal travel). A similar methodology would be used to compute intrazonal emission estimates. Route emissions can be summed to produce link-specific emission estimates. These emissions can then be either directly allocated to grid cells or apportioned on the basis of link length. The approach used to allocate zone-specific emissions to grid cells will depend on the level of intrazonal network definition that is available. Emissions within the zone, however, would be computed in a manner similar to that employed for interzonal travel.

Program Controls - A complex set of controls would be required to operate the proposed modeling system. Not shown, but implicit in the system, is a set of preprocessing steps that are needed to translate local information (e.g., travel survey, node coordinates, etc.) into a format that is compatible with the proposed modeling structure. The actual operation of the system would have to broken down into a series of steps that match the logical flow of information required to characterize local conditions (e.g., I/M program specifications, local registration data, travel parameters) and minimize computer system requirements.

###

3. COST IMPLICATIONS

This section presents a qualitative discussion of the incremental costs that could be incurred in developing the proposed modeling system. The critical elements to be considered when evaluating the costs of the proposed modeling system are as follows:

- Trends in existing and planned research that will generate the information needed to support the development of the proposed model. What information is already being developed, what information is not?

- New information requirements (e.g., testing programs) that will need to be produced on an annual basis that are not currently produced and therefore not covered in existing budgets.

- Staff requirements for developing and then maintaining the proposed modeling system. Can it be assumed that current staff used to maintain and upgrade existing emission factor models will be used in the development of the new modeling system?

- Any new system will require a substantial effort to educate local users. As the information requirements of the proposed system increase, so do the support costs for local users.

The modeling system recommended for development in this report is quite sophisticated and therefore will require substantial amounts of new information as well as a substantial development effort. In order to simplify the discussion of cost implications, the proposed modeling system is divided into three aggregate functional categories: transportation activity; emission factor development; and model integration. A brief review of the cost implications associated with each of these areas is presented below.

3.1 Transportation Activity

At the outset, it should be stated that this category has the greatest level of cost uncertainty. The primary reason is that the source of the money for transportation system model improvements is unclear. At present, the Department of Transportation has eliminated support for the Urban Transportation Planning System (UTPS) model. A new class of transportation planning models (e.g., MinUTP, System II, etc.) that can be operated on a wider range of computers has been developed by several consulting firms. These models are widely used by transportation

planning agencies in communities across the country. Unfortunately, none of these models appears to substantially improve the state-of-the-art in terms of the accuracy of intrazonal travel estimates.

Up until recently, there has been no specific demand for detailed estimates of this category of travel. Demand for this data, however, is growing as travel within local areas expands and communities struggle with the internal allocation of maintenance and road construction funds. Funds will be required to develop methods to quantify the travel occurring within TAZs. Additional funds will be required to modify or replace the existing models to incorporate these new methodologies. Funds will also be required to expand the network to include more information about local roads. While there are many potential sources of funds for this work, the key is that this is a new and at present unfunded area of effort.

Effort will also be required to develop the software that takes data from transportation planning models and organizes it into a consistent format that can be used in the proposed modeling system. It is unclear as to whether this effort can be satisfied with existing EPA staff or if it falls into a category of new expenditures.

The high cost of travel surveys limits the frequency at which they can be conducted. Many areas of the country conduct them on a 10-year cycle that may or may not be related to the Census. Some areas conduct them on 15-year cycles. The incremental cost of adding specific questions to collect data on soak times should not be particularly onerous. The level of effort required to improve the accuracy of intrazonal travel estimates would be more substantial. The key is where communities are in their current survey cycles. It is assumed that most agencies are already collecting the information that would be required by the TCM analysis module.

No TCM analysis module currently exists at the federal level. It appears that EPA does not plan to develop a module that can be integrated with the MOBILE series of emission factor models. Instead, a series of guidance documents is being prepared to help communities evaluate the benefits of alternative measures. As discussed earlier, California currently has an integrated TCM evaluation model. It, however, employs the emission factors produced in EMFAC7E. Because of the limited state of knowledge about the ability of alternative measures to influence trip behavior, the state-of-the-art should be described as in its infancy. A substantial effort will be required to track the state of knowledge as it evolves from the experiences of communities that experiment with alternative measures. It appears, however, that EPA is staffing up to track this information. Because it appears that EPA staff will be tracking this area of information, the costs of developing a TCM analysis module should not be particularly significant.

3.2 Emission Factor Development

This category of data and model development is expected to be the most expensive of the proposed modeling system. That is because (1) it is expected that EPA will continue to use either the FTP or some

modification of it (e.g., the addition of a bag 4 to represent high load conditions) to certify new vehicles and track their in-use performance and (2) a substantial testing effort will be required to characterize the engine maps of the on-road vehicle fleet. The collection of engine maps will thus not replace existing FTP-related activities, it will be in addition to them. This means that new staff/contractor support would be required to develop this information.

A substantial analytical effort will be required to determine the mix of engine maps needed to characterize new vehicle emissions, mileage deterioration and malperformance effects. A great deal of effort would also be required to translate existing I/M program modeling efforts from an FTP-based emission factor methodology to one that uses modal emissions. The translation of the activity and technology modules into the proposed modeling system should be trivial.

As discussed earlier, a substantial programming effort will be required to modify VEHSIME to quantify the emissions for a representative sample of engine maps for each link in unique routes. There is room for a great deal of creative thinking in how to minimize the programming requirements of the proposed system.

Finally, it should be pointed out that a large analytical effort will be required to analyze the data collected in the EPA and ARB chase car and instrumented vehicle surveys. This analysis will be required to produce the link-specific driving profiles that are a function of grade and congestion level. The above programming tasks can clearly be satisfied by existing EPA staff members. The cost of the effort will depend on whether the appropriate staff will be assigned the responsibility for the development of this software.

3.3 Model Integration

All of the remaining programming tasks (i.e., grid cell specifications and emissions, and overall system programming) will require a significant effort in order to make the modeling system available to a wide range of users. Again, it is unclear who will have the responsibility for the development of the overall modeling system. It appears, however, that this capability is resident within EPA.

###

4. VALIDATION

The proposed modeling methodology is based on the assumption that the accuracy of the travel estimates from the transportation planning models will be roughly equivalent to the accuracy of the emission factors produced by the modal emissions model. From the perspective of the emissions inventory, there is no reason for one estimate to have any more accuracy than the other. Because it is quite difficult, if not impossible, to use ambient air quality measurements to validate the results of the proposed modeling system (tunnel studies cannot be used to validate urban airsheds), it is proposed that effort be devoted to validate the results of the two principle components of the system: travel estimates and emission factor estimates. A brief description of the process that could be used to validate each component is presented below.

4.1 Travel Estimates

It is very difficult to validate a variable that cannot be measured. The problem of validating VMT estimates is not new. Compounding the problem is the fact that transportation planning models are not designed to predict VMT, they are designed to predict volume. A recent AWMA paper entitled "Travel Demand Forecasting Limitations For Evaluating TCM's" suggests that

> "travel demand forecasting models are calibrated and expected to be accurate enough so that the model's inaccuracies in the volume forecast will not affect the number of lanes when designing a highway project."

The paper goes on to indicate that typical error standards for regionwide ground counts should be less than 5 percent. The suggested error limits for functional classifications, however, range from less than 7 percent for freeways to less than 25 percent for collectors and frontage roads. The paper suggests that similar levels of error should be seen in VMT estimates. It cautions, however, that these estimates only cover the roads included in the network. The error for roads not included in the network but nevertheless included in an estimate of overall travel levels can be substantially higher.

The implication of this paper is that it is unreasonable to expect transportation planning models to evaluate the benefits of TCMs when the measure is expected to have an impact on travel that is lower than the accepted accuracy of the modeling system (i.e., 5 percent). This is an important perspective to maintain when evaluating proposed emission modeling systems. It is unclear what effect the suggested improvements in intrazonal travel will have on the overall accuracy of the transportation planning models themselves.

Sierra is aware of many approaches that have been used to independently validate local, state and national travel forecasts. These have included the use of fuel consumption estimates to back out travel activity, because fuel consumption is based on tax receipts. Another approach has extrapolated diary-based odometer readings for specific vehicle classes to represent travel for the entire vehicle population. Another approach relied on the use of annual changes in odometer readings from vehicles participating in I/M programs to represent travel as a function of vehicle age. All of these methods have had problems accounting for either fuel or travel that did not occur within the study domain. They have also had problems accounting for vehicles traveling through the study domain that are not locally registered. Therefore, the first step in the validation process of these models should be a thorough review of the literature.

The next step should be the collection of an extensive number of ground counts for an urban area that has a state-of-the-art transportation planning model with a 1990 or later base year travel estimate. The travel estimate should be based on a recently completed travel survey. The model can then be updated to reflect the road network in place at the time the ground counts were collected. The model can be validated with the normal level of ground count information. The results can then be compared with estimates that are based on the more extensive ground count survey to determine the level of accuracy the model has in representing travel throughout the urban area. This process can be used to develop an estimate of the accuracy of the model before and after the intrazonal travel estimates are improved.

4.2 Emission Factor Estimates

Of the two components, the emission factor estimates are the easiest to validate. The use of a modal emissions model allows estimates of emissions for any particular drive cycle to be validated through dynamometer-based measurements of emissions on the same cycle. There are, however, many reasons to expect that dynamometer-based emission estimates for a particular vehicle will not equal the values predicted by the modal emissions model. These can include differences between the selected vehicle and the technology represented by the emission map, the condition of the vehicle, and the accuracy of the selected start algorithm.

Both EPA and ARB are well aware of the fact that the modal emissions model cannot account for all elements of vehicle-specific emission control system performance. For this reason, EPA is planning to use VEHSIME as a screening tool to provide a rough indication of the emissions performance that a representative sample of vehicles would produce under alternative driving conditions (time/speed traces). On the basis of those preliminary indications, EPA will then test a representative sample of vehicles on dynamometers on the cycles that are determined to be of interest. The information developed in this process will provide the basis for a careful appraisal of the accuracy of the VEHSIME model.

ARB has plans to integrate a modal emissions model into its emission factor system (EMFAC/BURDEN). They also plan to use VEHSIME to evaluate the information developed in the ongoing chase car study. As stated earlier, the goal of that effort is to develop representative driving cycles for three peak periods of operation. One element of that study is a comparison between modal-based emissions estimates for those cycles and dynamometer measurements of vehicles operating on the same cycles.

The information developed in both the EPA and ARB efforts should provide the basis to evaluate the accuracy of the proposed modal emissions model. It is also expected that if these efforts discover significant discrepancies between the two measurements, further effort will be devoted to determine the source of the error and develop a methodology to correct it.

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APPENDIX F

Technical Report

CONCEPTUAL DESIGN FOR A NEW HIGHWAY VEHICLE EMISSION ESTIMATION METHODOLOGY

SYSAPP-91/083

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1 CONCEPTUAL DESIGN FOR A NEW HIGHWAY VEHICLE EMISSION ESTIMATION METHODOLOGY

BACKGROUND AND OBJECTIVES

Procedures that are currently used to estimate on-road motor vehicle emissions exhibit several significant limitations. These limitations compromise the accuracy of base year estimates as well as future year forecasts. Because the potential errors in emission estimates affect the predicted relative impact of mobile source emissions on ambient pollutant concentrations (especially for ozone), improving the accuracy of these estimates is a critical need. In addition, because of a reliance on a number of broad assumptions, existing emission estimation techniques can produce inaccurate predictions of the effects of specific controls, such as transportation control measures (TCMs) and alternative fuels. Many of the limitations of existing procedures arise from data, analyses, and models that are deeply ingrained in the mobile source emission estimation procedures; eliminating these problems requires a willingness to rethink each component of the process.

This report develops a conceptual design for a next generation emission modeling system for highway vehicles. The underlying objective for this specific conceptual design is to provide adequate support for air quality planning: source attribution; forecasting; control strategy evaluation; and verification of control strategy effectiveness. Meeting this objective requires:

Accurate base year emission inventories

Emission inventories that are resolved to levels that are appropriate for air quality analyses (i.e., to at least a few kilometers spatially, and one hour temporally)

Emission inventory forecasts that are accurate (within the ability to predict growth) relative to base year emissions

Control scenario forecasts that are accurate relative to the future year base case forecast.

Failure to achieve any one of these can lead to a systematic bias in the attribution of ambient concentrations to sources, and (depending on the selected controls) strategies that are unnecessarily costly, ineffective or even counterproductive.

In developing the conceptual design presented in this report, we reviewed recognized problems in current procedures, and possible approaches for addressing each. Subsequent sections of this report present:

An overview of recognized limitations of current approaches

The rationale for, and overview of our proposed approach

A description of the conceptual design of the emission model

Methods and issues in verification of inputs, relationships, and results

Anticipated research issues in model development and application

A summary of our recommendations

Three appendixes are included with this report:

A discussion of alternatives and capabilities for collecting information regarding in-use vehicles

A review of small-scale traffic simulation modeling alternatives and capabilities

A review of the methods and limitations of urban transportation planning models as related to the modeling of mobile source emissions.

2 A BRIEF OVERVIEW OF RECOGNIZED LIMITATIONS IN CURRENT PROCEDURES

The heart of the emission estimation process is the identification of an appropriate "vehicle term" and "emission rate term" for use in the equation

$$\text{Emissions} = (\text{Activity Level})\ x\ (\text{Emission Factor}).$$

For a single vehicle, there are several different causes of emissions, and therefore a number of different possible emission factor/activity level pairs that could be used. For example, hot-soak evaporative emissions can be estimated by multiplying an estimate of the number of grams of emissions per hot-soak by the number of trips that the vehicle makes. Tailpipe emissions can be estimated based on gram/mile, gram/minute, or gram/gallon of fuel, multiplied by the corresponding activity level for the vehicle. Similar options exist for running losses, excess cold-start and hot-start emissions, and breathing losses.

Both MOBILE4 and EMFAC7 (the U.S. EPA and California Air Resources Board emission factor models) treat these different emission sources, with EMFAC7 providing separate outputs for "trip-end" (hot-soak, cold-starts and hot-starts). However, emission factors from both models are aggregated to some extent (e.g., assuming constant speed for all vehicles).

The activity level parameters that are currently used to estimate emissions are derived primarily from data and models used in transportation planning. In their simplest form, these parameters are vehicle-miles-travelled (VMT) estimates for entire urban areas; more sophisticated emission estimates have been generated using transportation model outputs for traffic volumes and speeds on individual road segments, or "links." Like the emission factors, however, such estimates are still aggregated to some extent, such as by treating "average" peak hour or weekday average traffic volumes, and by estimating a single speed for each link.

Historically, the development of a fleet-average composite emission factor was necessary to develop emission inventories from limited available data. Recent studies suggest, however, that a much more explicit treatment of individual vehicles and operating conditions is now needed to accurately estimate emission rates. Several specific factors should be noted:

> Current emission control technologies such as closed-loop catalyst systems perform very well under moderate driving conditions (mild acceleration and deceleration, idle, cruise) but less well under hard acceleration.

Such control technologies appear to be optimized for the federal test procedure (FTP) driving cycle used in vehicle emission certification programs. Thus, departures from this cycle result in excess emissions.

A relatively small number of vehicles have been found in field studies to be contributing the majority of total emissions.

At the present time, then, the "average" composite emissions for the fleet appear to be made up of a relatively large, cumulative VMT for vehicles that are quite "clean," and a relatively small VMT for vehicles that are "dirty" either because of their condition or their current operating mode. Aside from questions regarding the actual accuracy of the estimates of "average" vehicle emissions, "average" link volumes, and "average" link speeds, we believe that a major problem with existing techniques is their failure to explicitly address those vehicles and operating modes that contribute most to total emissions. In particular, we believe that the proportion of atypically high emitters in different cities depends strongly on local factors. For example, the fraction of miles accumulated under heavy acceleration can be influenced by hills and highway geometry.

In summary, we believe that improvement in the accuracy of emission estimates hinges on disaggregation of both the "vehicle term" and the "emission rate term" in ways that allow explicit treatment of those conditions leading to high per-vehicle emission rates. This approach, of necessity, requires substantially more detailed information as input to the emission calculation, and the conceptual design of the proposed methodology is based on the objective of treating individual vehicles as explicitly as possible.

3 RATIONALE AND OVERVIEW OF PROPOSED APPROACH

The basis for recommending the proposed methodology is: (1) that current practices cannot reliably treat the range of important local factors that affect vehicle use; (2) that current practices cannot accurately describe emission rates for vehicles as used; and (3) the principal cause of these limitations is the reliance on overly aggregated representations of both vehicle operation and emissions. The primary approach for rectifying these problems in the proposed methodology is substantially increased reliance on empirical inputs, especially for vehicle operations.

Need for a Detailed Empirical Basis for Vehicle Operations

In order for such a method to succeed, comprehensive data on individual vehicle operations within an urban area are needed. We believe that a combination of techniques can meet this need. Principal reliance would be placed on the use of time-lapse aerial photography and computer image processing and analysis to determine, by roadway or subregion, such parameters as:

Number of vehicles in operation
Distribution of vehicle speeds by road type
Distribution of acceleration by speed and road type
Number of vehicles in non-freeflow conditions (queued and creeping, idling)
Number of trips started and ended.

Aerial photography and video data analysis for traffic flow have been recently explored in a number of contexts by Makigami et al. (1985), Becker (1989), Persaud and Hurdle (1988), and Taylor et al. (1989). Related studies include the vehicle classification and identification schemes reported by Pfannerstill (1989), Pursula and Kosonen (1989), and Williams et al. (1989).

Calibration and verification of this technique can be accomplished through the use of traffic counters and instrumented vehicles that can be identified in the photographs. The development of large-scale data bases of vehicle operations under a variety of conditions would provide a robust basis for operating mode distributions.

Value of Empirical Distributions of Vehicle Operating Modes

By basing the distribution of vehicle operating modes on data for the study area, the potential bias introduced by nonrepresentativeness of the generic FTP driving cycle can be prevented. Similarly, by using actual observed speed distributions on links, the arbitrary assignment of a single average speed to each link is avoided, as is the reliance on overly simplistic speed versus volume-to-capacity ratio relationships such as the BPR curve and the simplistic treatment of off-network travel (centroid connectors) as having a constant speed. Instead, the actual effects of local factors and conditions on vehicle operating modes are addressed. Such factors include lane width, road surface condition, distractions (road signs, commercial driveways and parking, on street parking, etc.), hills, and the level of aggressiveness of drivers. Such conditions are addressed in transportation models by attempting to calibrate the model's predictions to a limited set of observations.

At the urban modeling scale, much of the natural variability in vehicle operating modes is ignored on the assumption that driving cycle approximations provide a reasonable basis for describing operating modes. This simplification is not necessary. Empirical and mathematical descriptions can be generated to show these distributions. Figure 1, for example, shows speed distributions by time and location for a six-mile segment of a Los Angeles freeway. Matzoros (1990) has explored vehicle operating modes at intersections (Figures 2 and 3) for incorporation into a simple emission and air quality dispersion model based on modal emission factors and vehicle dynamics. The time-distance diagrams shown provide a potentially useful way of classifying vehicle operating modes from aerial photography under conditions where the transition deceleration to queue to acceleration may be ambiguous.

Modal Emission Rate Modeling

By replacing a nominal driving cycle with vehicle operating mode distributions, we eliminate the option of using driving-cycle-based composite emission factors. Instead, factors specific to vehicle operating modes are needed. Some work has been carried out in this area, and more will be needed in order to determine how to unambiguously establish the operating mode of a vehicle, and how emissions vary by mode. In this report, we suggest that modal emission factor models be developed whose primary input is a vehicle state vector consisting of basic mode (e.g., cruise or creep), speed, acceleration, and other relevant factors such as engine state (time since start) and canister loading.

Forecasting--Transportation Modeling Outputs as Parameters of Vehicle Operating Mode Distributions

To this point, the suggested approach is appropriate for base year estimates, but is difficult to use for forecasting due to the reliance on empirical vehicle operating distributions. Growth and congestion effects, as well as the effects of capital improvements to the roadway network

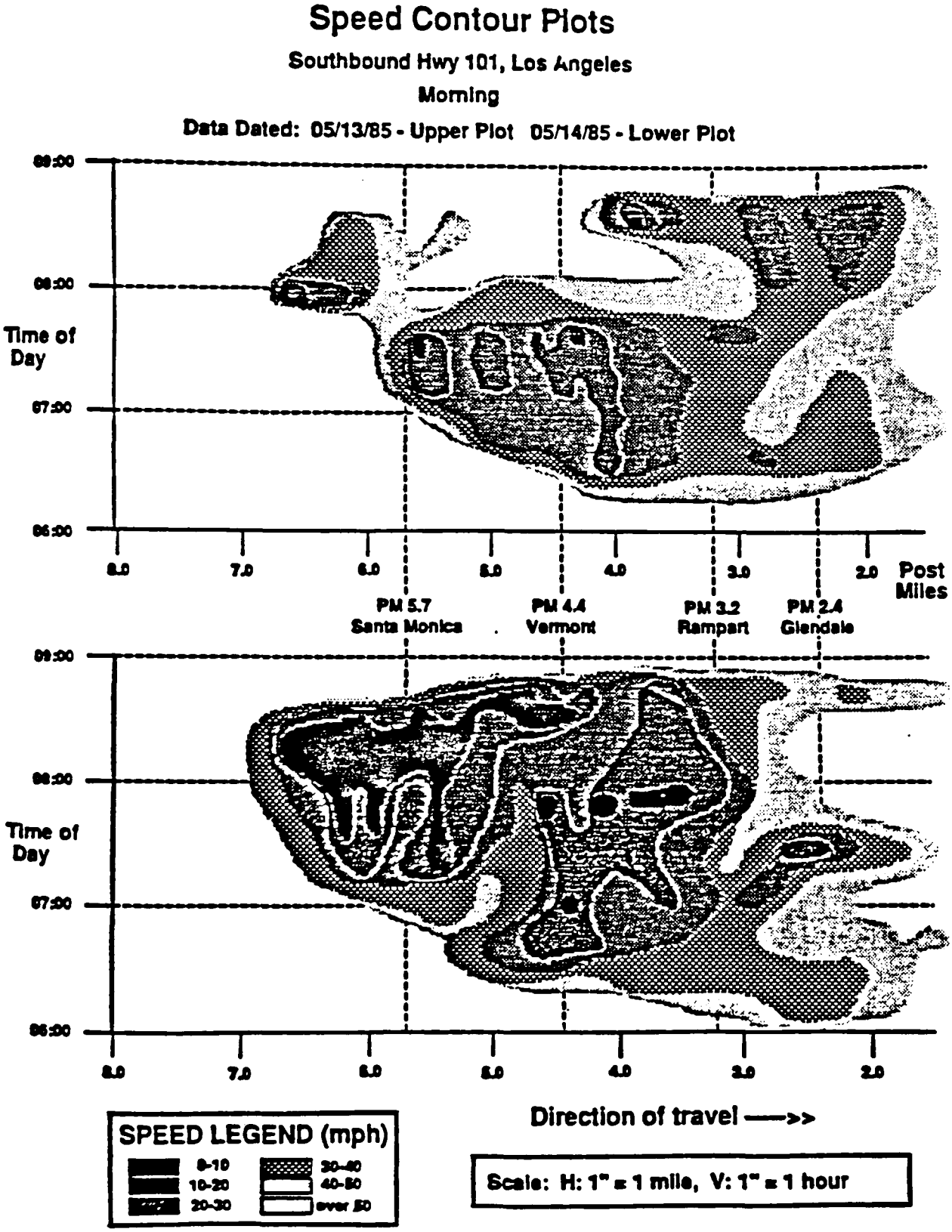

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FIGURE 1. Speed distributions over time along a freeway segment.

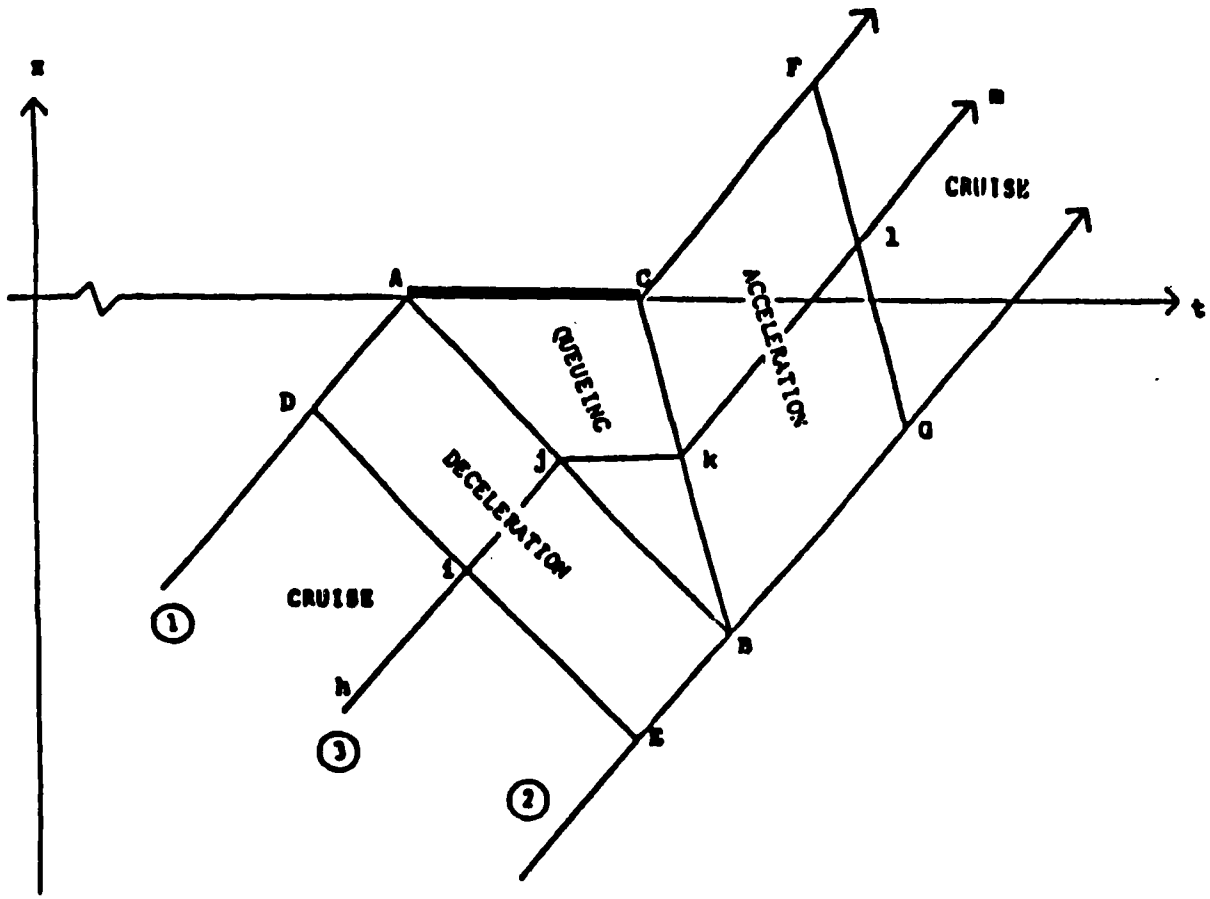

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FIGURE 2. Time-distance diagram showing operating mode trajectories for three vehicles at a signalized intersection (Source: Matzoros, 1990).

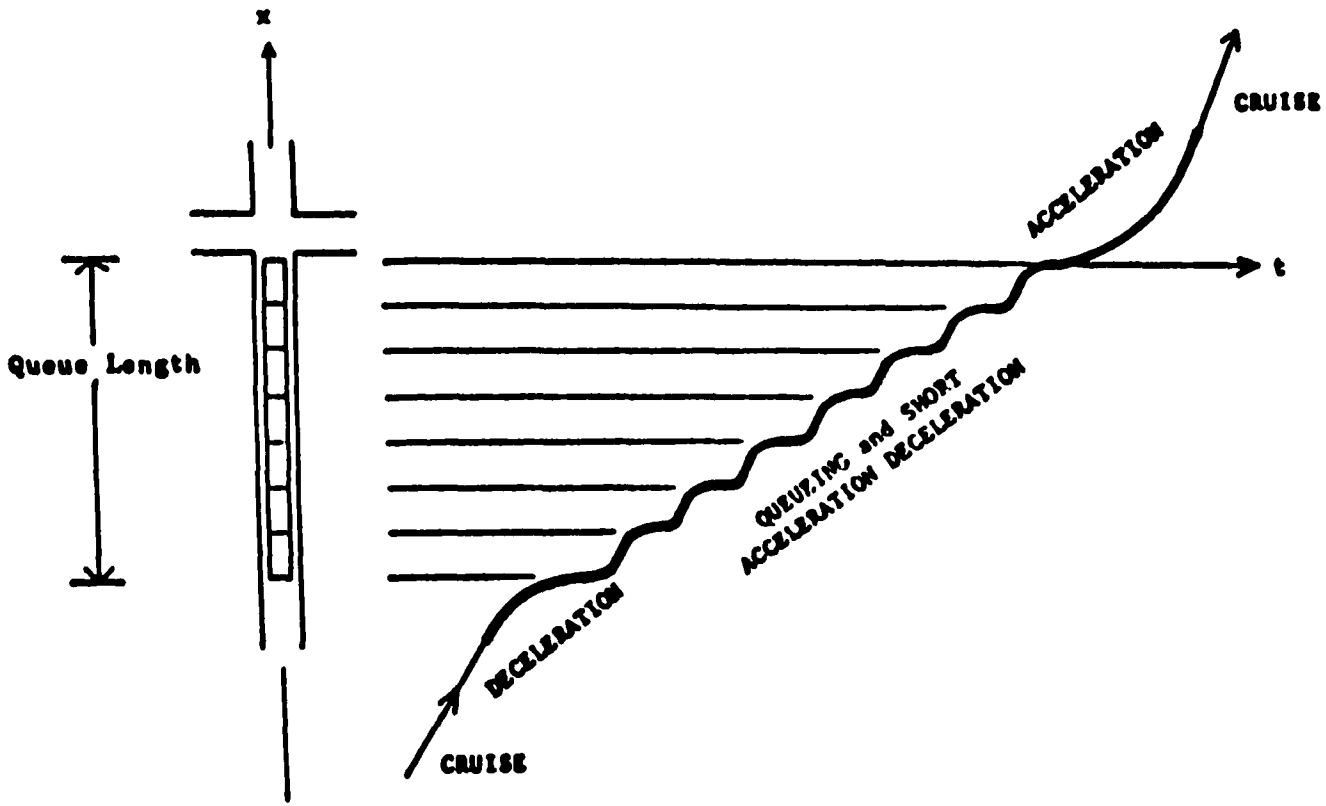

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FIGURE 3. Time-distance diagram for a vehicle approaching a stop-sign-controlled intersection (Source: Matzoros, 1990).

require the use of some form of model. However, it is not necessary to directly use the link-level transportation model outputs as the "vehicle term" for emissions. If sufficient data on vehicle operating distributions exist over a range of network loadings (e.g., over a range of times of day), relationships can be empirically derived between those distributions and transportation model outputs.

Objective: To Model Vehicle Operations or Roadway Performance?

The preservation of vehicle operating mode distributions is a major departure from traditional transportation modeling in several respects. The primary objective of transportation modeling systems is to simulate the operation of the highway network and assess its ability to handle travel demand. That is, the emphasis is on modeling of the facilities and systems. The transportation modeler has little need for knowledge of small scale fluctuations and variability--it is how the network behaves on the average that is important. In contrast, as discussed earlier, emissions may vary greatly for a specific average speed, depending on the distribution of speeds and accelerations that yield the average. Therefore, our objective is to describe individual vehicle operations, as represented by a multivariate distribution. The transportation model becomes an "instrument" for measuring the relative change in parameters that describe these distributions. In this way, the transportation model can be used as the basis for forecasting the effect of population and employment growth and network improvements on distributional parameters.

4 MODEL CONCEPT DESCRIPTION

Basic Emission Calculation

The computational structure of the proposed mobile source emission model is the numerical integration of emission rates, within designated areas, of a vehicle operating mode distribution and modal emission factor. This process is shown schematically in Figure 4. We use the following notation:

v	A vector describing the state and operating mode of a vehicle
$F_{ih}(v)$	The distribution function of vehicle operating modes within area i for hour h evaluated at vehicle state vector v.
$e(v)$	The emission rate (mass per unit time) for a vehicle in state v

The vehicle state vector consists of an identification of basic operating mode (cruise, idle, accelerating, creeping/queued), as well as continuous variables for key factors (speed, acceleration rate, canister state, engine/catalyst temperatures, etc.). For simplicity of notation, we will also assume that the vehicle state vector includes those terms usually used in defining fleet characteristics (model year, technology, mileage, etc.) as well as those describing current environmental conditions (temperature, relative humidity).

The emission rate for vehicles within area i for hour h is given by

$$\int_v e(v)\ dF_{ih}(v)\ .$$

Total emissions are given by the summation over areas (i) and hours (h):

$$\sum_{i,h} \int_v e(v)\ dF_{ih}(v)\ .$$

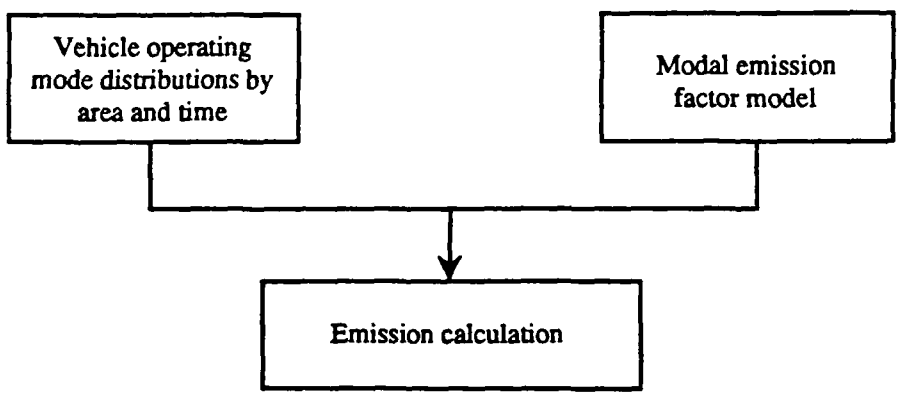


FIGURE 4. Base case emission estimation.

Base Case Emissions

The base case emissions for an area are based to the extent possible on empirical information. In particular, the vehicle operating mode distribution $F(v)$ is derived from detailed aerial photographic data. Time lapse photography (e.g., three frames at three second intervals) or video techniques can be used to determine the speed and acceleration of every vehicle within the photograph. Computer analysis techniques, coupled with geographic information systems (GIS) including roadway information, can be used to identify and extract these data. Although potentially time consuming, a relatively large and robust data base can be developed for any area, without the need for labor-intensive traffic observations or capital-intensive traffic monitoring. Since all vehicles are counted and their states determined at every point along roadways, questions of the representativeness of traffic count data are avoided.

This data base will also identify trip ends, in that newly parked or departed vehicles can be identified. This information on trip initiation/termination will be incorporated in the vehicle state vector distribution in a manner appropriate to the emission factor treatment. To avoid unnecessary repetition, we will not present here the emission rate equations for running losses, trip end emissions, or breathing losses; these are essentially identical equations to that already shown, differing only in the definition of the vehicle term v.

Development of Forecasting Relationships

Empirical distributions $F(v)$ are static, and cannot be directly used to develop future year forecasts. Transportation planning models can be used to forecast general traffic trends, but not distributions of key variables. However, in the course of developing empirical distributions through multiple hours and days of aerial photograph analysis, data will be collected that show the sensitivity of these distributions to variation in total network loading. For example, normal variations in day-to-day traffic volumes allow development of speed and acceleration distributions as a function of (for example) the total number of vehicles currently operating within area i, or the total VMT accumulation rate within area i. These data showing sensitivity to change provide the basis for forecasting.

To allow the use of transportation planning model outputs for forecasting, we define a new distribution $F'(v)$. This new distribution is a synthesized distribution based on a parameterization using transportation model outputs. Figure 5 shows the process for developing these distributions. We use the following additional notation:

w	A vector of parameters that are outputs of the transportation planning model and that correspond to measures of overall network loading in the data base used to develop $F(v)$
$G_{ih}(v \mid w)$	The observed distribution of vehicle operating modes v in area i for hour h, given that the network state is w

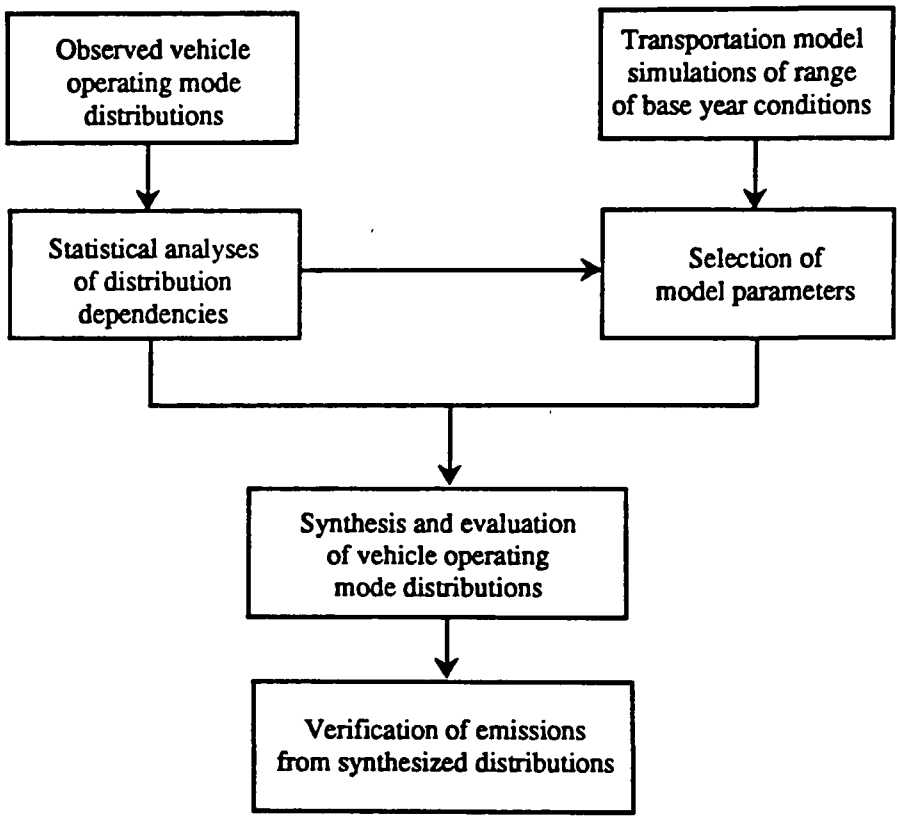


FIGURE 5. Development of relationships for synthesizing and forecasting vehicle operating mode distributions.

$G'_{ih}(v|w)$ A mathematically constructed distribution whose parameters are given by w that has been shown to be essentially identical to $G_{ih}(v|w)$.

Then

$$F'_{ih}(v) = G'_{ih}(v|w_0) ,$$

where w_0 is the "average network state" for the base case. That is, F' is simply G' evaluated under average base case conditions. It is clear that F' must be shown to give comparable vehicle distributions and emissions to those of F. It is also clear that the mathematical development of G' may be difficult, but can be simplified by limiting the dimensionality of w. In the absence of data bases of the type described for developing $F(v)$, the best approach for the development of G' is uncertain. The development of mathematical forms for G', the "calibration" of F', and the verification of agreement between F' and F will be a key aspect of developing forecasting capability based on this proposed approach. We do not explore specific methods here, but note that there are small-scale models (i.e., models that address individual vehicle operations within small areas) and model development efforts that are potentially useful in developing the needed relationships. For example, Wong (1990) and Rathi and Santiago (1990) describe the capabilities and structure of TRAF-NETSIM, a Monte Carlo simulation model of individual vehicle behavior within small networks.

Forecasting

The use of the above techniques to generate future year forecasts is straightforward, as shown in Figure 6. Denoting future conditions with an asterisk *, future year base case emissions are given by

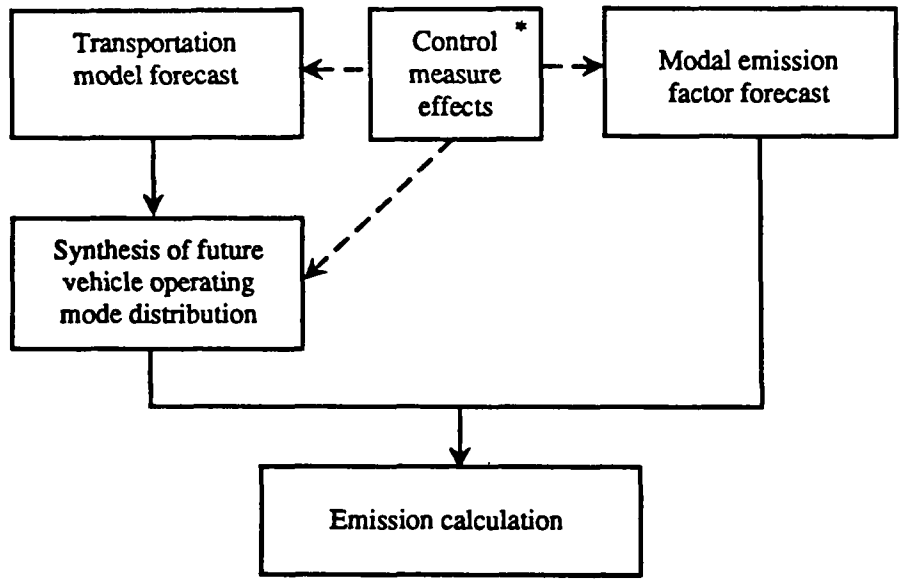
$$\int_v e^*(v)\, dF'^*_{ih}(v) ,$$

where

$$F'^*_{ih}(v) = G'_{ih}(v|w^*_0) .$$

Control Scenarios

The estimation of control effects under this proposed approach closely parallels existing practices. As shown by the dotted lines in Figure 6, there are three basic types of controls: those that affect vehicle emission rates (e.g., retrofit technologies, reformulated fuels); those that affect trip generation (e.g., ride sharing measures, growth management strategies); and



* Control scenarios only.

FIGURE 6. Development of future year emission forecasts.

those that affect vehicle operations (e.g., flow improvements, elimination of driveup windows). Depending on the specific measure, simulation of controls could involve either the modal emission factors (e.g., for reformulated gasoline), the future year transportation model forecast parameters w (e.g., for employer-based trip reduction); or the relationship between transportation forecasts and the synthesized distribution of vehicle operating modes, $G'(v|w)$.

The disaggregate nature of emission calculation via numerical integration allows explicit treatment of factors whose effects might otherwise be treated in overly simplistic ways. For example, modal emissions for vehicle idling can be directly treated in a modeling system that explicitly treats the number of vehicles idling at traffic lights. The principal limitations of providing this opportunity arise from both the computational intensiveness of any such changes, and the need to generate reliable estimates of vehicle operating mode distributions. Small-scale transportation models were previously mentioned as having the potential for addressing the effects of, for example, travel demand or signal timing on distributions of acceleration, idle, creep, and cruise modes. Such models become important here for two reasons: (1) the initial data on which G' will be based will be of relatively short duration and will not be able to statistically support estimation of the effects of all types of flow improvements; and (2) the vehicle operating mode distribution F' must provide a reasonable representation of changes arising from system changes that expedite or impede flow.

5 VERIFICATION OF INPUTS, RELATIONSHIPS, AND RESULTS

The historical failure of emission estimation procedures to provide accurate values is cautionary. Each step in the estimation process should be subjected to independent verification of its performance under actual conditions. The proposed approach offers opportunities to verify individual steps and components of the emission calculation. We will consider the individual parts of the emission estimation process independently.

Vehicle Operating Mode Distributions

Photographic and image processing techniques for establishing vehicle operating mode distributions have been explored, but they cannot be considered to be standardized. However, a number of opportunities exist for evaluating the performance of such techniques. These include

> Equipping marked vehicles with accelerometers, fuel consumption and emission measurement instruments, and position recording equipment, and verifying the accuracy with which aerial photographic techniques estimate mode, speed, acceleration, and emissions. This technique can also be used on a "trip" (as opposed to area) basis to identify spatial differences in operating mode distributions, and as a check on the areawide distributions of operating modes.
>
> Conducting "audits" using video techniques, loop counters, and other fixed-location data, to determine how accurately the primary method describes roadway dynamics.
>
> Use of video-based license identification techniques (Williams et al., 1989) to verify the age distribution of in-use vehicles, and the variability of this distribution by time and location.

Note that although these methods are useful to test and verify the accuracy of the primary technique, it is not necessary that they be found to be "representative" of typical conditions in order for them to be of value for verifying performance of the emission estimation method. This cannot be said of such techniques if they are ultimately directed toward a nominal driving cycle such as that of the FTP.

Modal Emission Factor Model

The development of emission factors has been a perpetually troublesome step, and will remain so until reliable methods for in-use vehicle emission measurements have been developed. Nevertheless, the use of modal emission factors allows more direct comparison of vehicle-specific emission rate measurements with predicted values. The Stedman and Bishop (1990) remote sensing technique shows promise, especially in conjunction with registration-based identification of vehicle age and technology. As noted in the preceding paragraph, test vehicles can also be used to verify the accuracy of model-based emission estimates of single vehicle emissions.

Synthesized Distributions of Vehicle Operating Modes

As noted earlier, this is perhaps the area where the most new development work is needed. Small-scale models of roadway dynamics will need testing and verification. In addition, the ability to synthesize operating mode distributions is a severely multidimensional problem. It cannot be arbitrarily assumed that traffic dynamics are independent of factors that are primarily of concern for emission rates (e.g., vehicle size and age). Early work is needed to determine the extent to which independence of traffic dynamics and vehicle or area characteristics can be established. For example, if it can be shown that systematic bias in the joint distribution of speed and acceleration on freeways (given fixed volume) is independent of time of day and area, then the development of synthesized distributions is greatly simplified.

As part of this effort, parameterization based on transportation planning models is needed, along with verification that the use of outputs from such models as inputs to smaller-scale models yields appropriate distributions. This is perhaps the weakest area of any forecasting technique, in that the "vehicle term" that is generated is a traffic modeling forecast of a traffic modeling forecast of a socioeconomic forecast. Errors in such forecasts are to be expected. Appropriate checks are needed to verify that the procedures followed produce an ultimate product (the synthesized distribution F') that is properly sensitive to the key inputs: travel demand and network status. Maximum use should be made of the natural (day-to-day and seasonal) variation in travel volumes to establish operating mode distributions over as wide a range of network loadings as possible. These data can then be used to test the performance of model-synthesized distributions for heavier loading and roadway improvements. Similarly, planned road maintenance closures can be treated as experiments to determine the sensitivity of operating mode distributions (both empirical and synthesized) to changes in overall network capacity, and other planned experiments (e.g., signal timing) can be conducted.

Finally, although there may well be errors in absolute forecasts, the opportunity exists (with appropriate data collection) to verify the basic procedures. On a year-to-year basis, it can be determined whether the procedures for forecasting vehicle operating mode distributions

would have reproduced those that were actually observed, if the area-wide forecast itself had been correct.

6 RESEARCH ISSUES

Much of the work needed to develop this proposed emission modeling concept has been recently explored, or is currently underway. This is not to say, however, that an integrated program can be immediately assembled from existing data bases, tools, and programs. Research strategies for developing modal emission factor models for in-use vehicles are not yet integrated with traffic engineering efforts to describe vehicle dynamics. Similarly, transportation planning models have been used to provide inputs for smaller scale models, but treatment of distributions of vehicle operating modes has been avoided. Where the stochastic nature of traffic flows has been treated, such as by Daly and Ortuzar (1990) and Chang and Kanaan (1990), the emphasis has been on the effect of sample size, level of aggregation, and model complexity on error bounds and confidence limits for model-predicted transportation parameters.

An integrated effort will be needed to develop the proposed emission estimation approach. Common definitions of terms and variables is needed, as is careful review of the capabilities and limitations of each of the data collection and modeling techniques. An important step is the development of an operational definition of vehicle operating mode that is appropriate from the perspective of traffic data collection, traffic modeling, and emission modeling. We have suggested by way of example that four basic modes (cruise, acceleration, idle, and creep) be used along with other variables to define vehicle operating modes. Other ways of dimensioning the vehicle mode state space may be more readily integrated with traffic data and modeling.

Defining characteristics or boundaries for subareas will also require careful attention. Arbitrary gridding of an urban area is feasible, but may lead to difficulties if an individual areas' traffic behavior interacts too closely with its neighbors, or if an area is too diverse to exhibit consistent patterns. Definition based on roadway characteristics is not an option, unfortunately, in that there is a clear dependence of traffic flows on different types of roads within an area. This interaction (e.g., spillover of freeway traffic onto arterials during congested periods) makes it impossible to separately treat adjacent roadways.

Many other research areas arise from the suggested approach, including the prospect of developing weekend emission simulations (unreliable to date), and exploring the "normal" variability in traffic volumes and emissions from day-to-day. For example, weekday/weekend effects in ozone trends are well established; how significant in determining maximum ozone concentrations is the coincidence of adverse meteorology and abnormally congested traffic networks? Palen (1989) shows that at least at the roadway level, substantial

variation from day to day is possible. Development of emission factor models based on the physics and chemistry of combustion and controls is another potentially fruitful area. Comparability of vehicle operating mode distributions within and across cities will be of particular interest as well. Although descriptions of human driving behavior cannot be developed from physical principles, the large number of vehicles, and the basic physical constraints of cars and roadways may make it possible to develop mathematical forms that describe the stochastic nature of vehicle operations in ways that are applicable in all areas.

7 SUMMARY

In this report, we have suggested a conceptual design for a next-generation mobile emission modeling system. Although it draws from current work, the proposed system places substantial reliance on detailed empirical distributions of vehicle operating modes as the primary vehicle-related input to the calculation. The intent is to simulate individual vehicle operations, rather than VMT accumulation. In this way, potential unrepresentativeness of arbitrary driving cycles does not influence emission calculations.

This approach requires the development of a modal emission rate model whose input parameters are consistent with those that define vehicle operating modes. Given the distribution of vehicle modes and the modal emission model, it is possible to numerically integrate over the range of possible vehicle states to develop emission estimates. If properly defined, and with adequate data, such estimates provide explicit treatment of many of the factors that are not currently treated in mobile emission forecasts.

Forecasting under the proposed system requires the use of transportation planning models and small-scale models to synthesize distributions of the base case emission inventory (for purposes of verification). This hybrid approach (i.e., model-based synthesis of empirically developed distributions) may require substantial testing and development, but has several advantages. Most notably, since distributions of vehicle operations are preserved, overly simplistic treatment (from an emission modeling perspective) of vehicle operating conditions is avoided.

The proposed approach is both data and computationally intensive due to the size of the data bases involved. However, advances in computing speed, and the ability to automate much of the data reduction and analysis (e.g., through computerized analysis of video images) should substantially reduce costs, as well as enhancing data comparability between cities. Substantial reliance is also placed on aerial photography for data collection. While high-resolution (and costly) mapping and surveillance techniques could be used, adequate results should be achievable with substantially less expensive platforms. The development of base case emission inventories should be relatively inexpensive in that no transportation modeling is required. Additional costs (e.g., use of instrumented vehicles and remote sensing to verify in-use emissions are those that should be anticipated, regardless of the design chosen for the emission estimation system. The costs of forecasting are likely to be substantially higher for the first city studied, due to the need to explore the ability to synthesize vehicle operating mode distributions from traffic model outputs. Such efforts should be transferable to other cities, however, resulting in an overall emission forecasting system whose costs are comparable to those expended in transportation modeling.

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APPENDIX A

COLLECTION OF DETAILED VEHICLE IN-USE INFORMATION

INTRODUCTION

Given the significance of driving cycle information to the emissions modeling efforts, significant data collection efforts over the next five years should be devoted to ascertaining real world driving cycles under a variety of conditions. Certain developments in the traffic engineering environment may provide a useful base for our efforts.

POSSIBLE STUDIES

Monitoring of Vehicles by On-vehicle Sensors

The objective of this study is to extend current technology as required to facilitate the placing of a "black box" in either a series of test vehicles who would drive standard courses throughout the city, or, with more advanced technology, place recording devices on a random sample of vehicles in several urban areas. Devices should record time and speed information for periods of at least a week.

Several projects reported in the literature have done related activities. Palen (1989) reports a massive study where test vehicles were instrumented to measure fuel consumption on a variety of test runs over a carefully monitored section of highway. Link volume data was collected by various passive count devices. The study derived various relationships of vehicle performance to fuel consumption and evaluated other models. The data set is available to other researchers.

Monitoring of Selected Urban Links

The objective of this activity is to develop monitoring techniques of actual vehicles to record and assess the dynamics of interest for emissions. Vehicle monitoring has been conducted for decades. There are four principal methods:

Manual counting
Fixed position sensors in or on the roadway
Fixed position camera

Aerial photography, including helicopters, airplanes, and blimps.

Manual counting.
This requires the least technology, but really records only count data. If sufficiently detailed (turning movements, vehicle types, number in queue) it might support other studies, but is not sufficient in itself.

In-road sensors.
While this is primarily a way of obtaining counts, some research has been done (see Pursula 1989) at using the analog signal of a loop detector to measure vehicle class.

Photographic techniques.
It seems clear that for the assessment of the vehicle dynamics of acceleration, deceleration and idling, more detailed observations are required. Filming traffic movements for later data reduction is a technique that goes back to the 70s, or further. The cost of film and the difficulties of reducing data to a computer processable record have prevented widespread use of this technique. Both limitations are being eased. The reduced cost of video equipment and the advent of computerized methods of deriving data from video are spurring current research.

Persaud (1988) reviews the history and feasibility of this approach, and reports a project to obtain data on variations in speed as a function of flow and location and discusses methods of extracting data from film. Taylor (1989) reports on acquiring headway and speed information via video and describes computerized techniques for automatic data reduction from the video record. The specific possibilities of aerial photography are explored, in among other places, Becker (1989) and Makigami (1985).

One development that could greatly expand the information available to analysts is the possibility of automatic number-plate recognition and matching. With several video cameras, and linking to registration databases, it is possible to both determine the actual routes and elapsed time on routes for vehicles and the exact mix of vehicle classes traversing the routes. Work in this area is described by Williams (1989) and by Pfannerstill (1989).

Given the current ferment in research on image processing and the declining cost of video equipment, there would be a likely opportunity for significant advances in this area with funding. Note in particular that work is already focusing on obtaining some dimensions of vehicle dynamics necessary for the emissions modeling effort.

QUESTIONS FOR DATA EVALUATION

A research task could be formulated to use and generate monitoring data focusing on the needs of emissions analysis. Some specific questions to guide these data collection tasks are given here.

What is the extent and nature of temporal and spatial variability on the pattern of driving cycles?

What is the significance of vehicle class on driving cycles? Specifically, how many divisions of vehicle class are necessary due to different driving dynamics and how does that relate to the vehicle classes used in emissions analysis?

Is roadway type a significant indicator of driving cycle? This would be particularly useful if true, since roadway type can be obtained from map data.

Does link congestion dominate other variables in the assessment of driving cycles? In other words, can we use link volumes as proxies for driving dynamics?

APPENDIX B

SMALL-SCALE TRAFFIC SIMULATIONS

The UTPS and similar transportation planning modeling systems are oriented toward urban scale modeling. They cannot deal with the dynamics of individual vehicles, nor is that their purpose. There are many other models of traffic operations that provide better platforms for analyzing the detailed dynamics that play such a significant role in emissions. We review these for their suitability for providing a platform for our efforts.

SPECIAL PURPOSE SIMULATIONS

There are myriad special purpose simulations that model a particular roadway situation. As an example, Zarean (1988) reports the development of WEAVSIM, a model of freeway weaving sections. These might be useful for specific studies, but are not general enough and are not supported and documented at a level necessary to be used by the wider community.

GENERAL SIMULATIONS

More general are those simulations that can be configured to describe a section of road network and are flexible enough to deal with small scale issues like turning lanes, delay from parking vehicles, and so forth. Key among these are CONTRAM, developed in the U. K. (see Leonard, 1989, and Taylor 1990) and NETSIM, now TRAF II NETSIM in this country (see Rathi, 1990, Wong, 1990, Michigan Dept Highways, 1987).

These models are primarily intended for the modeling of changes to the transport system to investigate impacts on capacity and delay. One very significant class of changes of concern to traffic engineers has to do with traffic signal light timing.

As NETSIM is supported by FHWA, we focus our assessment on this model. NETSIM was developed in the early 1970s, and has been applied to a variety of problems throughout the U.S. Individual vehicles are modeled on a 1 second timestep. Various classes of vehicles are supported. The model captures various detailed movements such as turning across opposing traffic, reacting to obstructed lanes, yield and stop signs and pedestrian delay of vehicles. Reflecting its traffic engineering perspective, there is a very detailed ability to model traffic signals. Some emission modeling capability is included.

SUITABILITY OF TRAF II NETSIM

A preliminary assessment of descriptions of NETSIM show that it has potential to be modified to serve as a platform for supporting emission modeling. NETSIM does model individual automobiles, and allows for variation in driver dynamics, albeit at a simple level. Approach and departure from intersections is governed by a simple deceleration and acceleration formula, giving access to these dynamics. The modeling of fuel consumption involves calculations that have some similarity to what we expect for emissions. It would certainly support modeling of a variety of TCM measures relevant to emission controls.

However, certain extensions would need to be made to NETSIM, based on our current understanding of the model. More complex deceleration and acceleration curves may be needed, and changes in simulation outputs would be required.

APPENDIX C

THE URBAN TRANSPORTATION PLANNING SYSTEM

INTRODUCTION

Given the intimate connection of estimating the spatial and temporal emissions of automobiles with the transportation modeling problem, it is essential for emission modeling to understand the dynamics of the transportation problem.

After thirty years of effort, the current state of urban vehicular modeling can be summarized by saying that there is a default modeling framework, and intensive investigation of alternatives to it.

The default system is known as UTPS, the Urban Transportation Planning System. This is a set of related computer programs that implement the default modeling techniques. The history of UTPS is covered in the two reports of Dial (1976) and Weiner (1988). A case study using UTPS was published as UMTS (1986).

As we review this system, we will evaluate its suitability for the emission modeling effort, and review various alternative methods currently undergoing research.

FUNDAMENTAL ASSUMPTIONS

Inputs

The default modeling approach takes as inputs various socioeconomic data, a description of the road network at the individual street level, and an empirically derived relationship between travel time and the likelihood of a trip being made. There are four primary data sets required:

> Transport Network. A link and node description of the highway and transit network. Primary link characteristics are: end nodes, length, maximum speed, capacity per lane, lanes. Primary node characteristics are x, y coordinates. Note that artificial nodes for zone centroids and links from zone centroids to a real node are required.

Zone Data. These consist of information that will be used to predict the attractions (number of trips ended) and productions (number of trips started) in each zone. They are typically derived from a regression analysis of various factors. Productions may be modeled as a function of population, income, number of autos, household size and other factors. Attractions may be modeled as a function of square footage in the zone devoted to retail, manufacturing, etc. Trips may be modeled by type (home-based work, home-based shop, non-home-based, etc.). Note that zones are seldom, if ever, a regular X,Y grid, and they do not correspond to grid cells of air pollution models.

Friction Factors or Travel Time Factors. These are a set of points that define an empirical curve that describes the way travel time affects the attractiveness of a trip. In other words, using the metaphor of the gravity model, these curves define how the "force of gravity" falls off as travel time increases.

Travel Survey Data. Various travel survey data for the base case or previous years are needed. These may be used, prior to forecasting applications, to derive the friction factors and to calibrate base case results.

Outputs

The primary outputs of the UTPS system are link volumes and travel times for a single point in time of equilibrium flow. From the perspective of emission modeling, this is at once too little and too much. It is too little because emission modeling requires temporal disaggregation into time of day, and because of the importance that acceleration and deceleration play in the emission process. Further, if the primary acceleration, deceleration, and idling times are associated with stopping for intersections, then the focus of UTPS on links may not be modeling the particular points of concern.

On the other hand, it is too much because we are really not interested in link volumes as much as flows in a grid cell.

BASIC MODELING STEPS

The standard modeling process implemented in UTPS involves a classic four-stage process: trip generation, trip distribution, model choice and route choice. The stages are sequential, so the results of a downstream stage do not influence the upstream stages. We consider each stage in more detail.

Preliminary Activities

Before the model can begin, certain preliminary efforts are required which also have implications for emission modeling. First is the preparation of the network. For a major urban area this could be enormously complex, even if residential areas were not completely modeled. However, this has been done for urban areas that have been using UTPS for some time. Further, the development of computerized mapping techniques and the use of GISs simplifies this process.

Of more significance, however, is the construction of zones. This immediately defines the level of aggregation of data. Each zone has a centroid, which is connected to the real network by an artificial link. These artificial links are the sources and destinations for trips within the zones, and are used to describe all travel that does not occur on identified real links.

Trip Generation

How many trips are there in an urban area? This stage generates origins (productions) and destinations (attractions) by zone. Typically, a multiple-regression analysis is used to form an equation relating productions and attractions to various socioeconomic criteria. Developing this model may depend on some sort of traffic survey or more general household survey. These surveys are so complex and expensive that they are performed only every twenty years, or have limited resurveys every ten years.

The zonal approach to trip generation is a fundamental assumption which has several consequences on the shape of modeling. First, it should be noted that this is not a behavioral model. The "zone" is not an entity which decides to make certain numbers of trips. The number of trips is an aggregate of various individual decisions which one hopes, with some expectation, will result in correlations at the zonal level. Also, the condition of the transport network itself, fuel availability and price, have no impact on the number of trips, something which is clearly true only in the short run.

Trip generation models become quite complex, since each type of trip (home-based work, recreation, non-home based, etc.) generally has a separate model. For an example of this complexity, see Kollo (1989).

Trip Distribution

Trip distribution is the linking of origins and destinations. Each production in a zone gets assigned to an attraction in another zone. The classic technique here is the gravity model, first described by Alan Voorhees in 1955. The gravity model calculates the trips between each zone pair using the "attractiveness" of the destination zone divided by the sum of "attractiveness" of all the destination zones for the origin zone. "Attractiveness" is a

function of the actual attractions in the destination zone, the friction factors, the minimum travel time on the minimum path between the zones and a further factor. This last factor is calibrated on the base case data to make the model converge to observed data.

There are a number of obvious issues here. While the choice to make a trip and the choice of where to go may be separable without difficulty for work trips, it makes less sense for non-work trips, where the choice of destinations and the ease of getting there can dramatically affect the number of trips themselves.

Travel Mode Split

The third stage is to split trips by mode (e.g., single occupant vehicle, transit) as a function of time and cost of travel, although the user may specify the exact form of the model.

Trip Assignment

This step distributes trips by link according to the following process:

> Assign trips to best paths using minimum travel time
>
> Calculate link volumes
>
> Adjust link travel times based on congestion
>
> If the change in travel times has converged to an acceptable level, quit, or else go back to step 1 (assignment of trips), using the new link travel times.

As with the other stages, the assignment process has been critiqued. Note that each trip loads each link from origin to destination simultaneously rather than being an individual vehicle which flows over the network. Further the artificiality of the loading of the network and searching for equilibrium has resulted in various algorithms being proposed for how the network is to be loaded. More behaviorally based models of traffic assignment have been proposed (see Antonisse, 1989).

NEW APPROACHES

Two directions of alternatives to UTPS may be briefly noted. First, models aimed at combining the various stages are common, for example see Ali Safwat (1988) and the literature cited there.

A second approach is to abandon the zonal framework altogether and make the household the basic unit of modeling. Aggregate statistics are then based on sampling over the urban

region. This approach first arose in the context of sketch planning. See Ben-Akiva (1985) and the literature cited there.

GENERAL ISSUES FOR UTPS

There are some additional issues, and key working assumptions of UTPS which are well known by practitioners:

Multi-Segment Trips

Trips of more than one destination (x to y to z) are modeled only by breaking them into single segment trips. The chaining of trips can be significant (e.g., as a reaction to higher gas prices or scarce availability); this change must be handled externally rather than being modeled.

Varieties of Vehicle Types

Travel is classified by trip type, but vehicle type is not addressed.

Information Availability

The ability of drivers to know the current state of congestion is not modeled. One proposed TCM is to improve driver information to permit a reduction of idling and congestion.

Time Dynamics

This is a steady state model, and not one where temporal issues are considered (e.g. leaving early or late to avoid the rush). The trips happen all at once. However, note that peak versus off-peak periods may be modeled separately.

SUITABILITY FOR EMISSION MODELING

While UTPS, when used by knowledgeable and skilled analysts, produces better results than might be supposed based on the preceding discussion, the model framework is of limited value for emission modeling.

If link volumes, the primary output of UTPS, are to be used as a basis of emission modeling, then a significant analytical effort must be developed to understand the connection between an average link volume and the complex of vehicle operating dynamics that determine emissions.

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16. ABSTRACT The report discusses six conceptual designs for a new highway vehicle emissions estimation methodology and summarizes the recommendations of each design for improving the emissions and activity factors in the emissions estimation process. The complete design reports are included as appendices. EPA asked six contractors to assist in developing ideas for a potential methodology to estimate highway vehicle emissions that could be developed for use in 5-10 years. They were selected because of their experience in working with mobile source emissions inventories. In general, the contractors suggest developing new modules within the emission estimation process to provide users with more detailed information on the causes of vehicle emissions. The essence of these concepts is the need for more comprehensive integration of data between the transportation planning model and the emission factor model. The individual reports did reinforce comments voiced by other experts for modal data and more responsive transportation models, although they did not identify totally new concepts not already being considered by EPA research programs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Motor Vehicles	Stationary Sources	13F
Emission		14G
Estimating		
Mathematical Models		12A

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