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16. Abstract Air quality nonattainment areas must use computer models to estimate the mobile source portion of emission inventories for the State Implementation Plan. Mobile source emissions estimates are produced for the emission inventory by multiplying an emission factor by a measured vehicle activity (such as vehicle miles of travel). The Environmental Protection Agency requires the use of their model, MOBILE, to produce emission factors for all states except California. California uses their own emission factor model, EMFAC. Travel demand models, used for transportation planning, produce the needed vehicle activity data. Emissions modeling systems act as an interface between the emission factor models and travel demand models, pulling data from both models to calculate mobile source emissions estimates. This report describes emissions modeling systems that are currently being used or have recently been used for air quality analysis aspects of transportation planning. Both MOBILE and EMFAC are described, and concerns about the accuracy of their emission factors are reported. Each emissions modeling system is described, including major inputs and outputs, and which emission factor model and travel demand model the emissions model will interface with. The authors evaluated each emissions modeling system for possible use in Texas, and found that none of them offer significant advantages in features, accuracy, or ease of use over the emissions modeling system currently being used in Texas.					
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**STATE-OF-THE-PRACTICE REPORT ON
MOBILE SOURCE EMISSIONS MODELS**

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Research Report 1279-3
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Transportation Investment Decisions

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IMPLEMENTATION STATEMENT

Emission factors are crucial elements in producing emission estimates. This report provides information on the emission factor model, including its shortcomings, required by the Environmental Protection Agency. Information is also provided on California's emission factor model and the different results it produces with the same kinds of data used by MOBILE. Although measurements from the emission factor models and emissions models are described in metric units throughout this report, the models themselves use English units; however, emissions are reported in grams by the models.

Air quality modelers can use the descriptions of emissions modeling systems and emission factor models provided in this report to evaluate the best combination of models to use in their modeling domain. After evaluating the various models, the authors recommend that the Texas Department of Transportation continue using the PREPIN/POLFAC/IMP SUM/SUMALL package, which has been used in the El Paso, Beaumont-Port Arthur, Victoria, Austin, and Houston-Galveston-Brazoria modeling areas.

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The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. Additionally, this report is not intended for construction, bidding, or permit purposes. Raymond A. Krammes, P.E., #66413, was the Study Supervisor for the project.

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LIST OF ABBREVIATIONS AND ACRONYMS

$\mu\text{g}/\text{m}^3$	micrograms per cubic meter
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
ATP	Anti-Tampering Program
BER	Basic Emission Rate
BIOME	Biogenic Source Model (part of GEMAP)
CAAA	Clean Air Act Amendments of 1990
CALIMFAC	California I/M Emission Factor
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CB-IV	Carbon-Bond
CO	Carbon Monoxide
DTIM	Direct Travel Impact Model
E7FWT	Weight Program
EPA	Environmental Protection Agency
EPS	Emissions Preprocessor System
F	Fahrenheit
FTP	Federal Test Procedure
g/hr	grams per hour
GEMAP	Geocoded Emissions Modeling and Projections (larger part of MoVEM)
GIS	geographic information system
HC	Hydrocarbon
I/M	Inspection and Maintenance
INM	Inspection and Maintenance Program (an input for IMPACT)
IRS	Impact Rate Summarization
kph	kilometers per hour
LAP	local area parameter

LAV	Link Attribute Value
LAVDATA	Link Attribute Value Data (an input file for TRFCNV)
lbs.	pounds
LMOS	Lake Michigan Ozone Study
MERF	model emission record format
MoVEM	Motor Vehicle Emission Model or Motor Vehicle Source Model
mph	miles per hour
NAAQS	National Ambient Air Quality Standards
NCTCOG	North Central Texas Council of Governments
NJDOT	New Jersey Department of Transportation
NMHC	Nonmethane hydrocarbon
NO	Nitrogen Monoxide
NO ₂	Nitrogen Dioxide
NO _x	Nitrous Oxides
PC	personal computer
PM-10	Particulate Matter (over 10 micrometers in diameter)
PPAQ	Post Processor for Air Quality
ppm	parts per million
RVP	Reid vapor pressure
SAI	Systems Applications International
SARMAP	San Joaquin Valley Air Quality Study/Atmospheric Utilities Signatures, Predictions and Experiments Regional Modeling Adaptation Project (see MoVEM section)
SCC	Source Classification Code
SIP	State Implementation Plan
SO ₂	Sulfur Dioxide
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
UAM	Urban Airshed Model
UTM	Universal Transverse Mercator

UTPS	Urban Transportation Planning Study
VHT	vehicle hours of travel
VMT	vehicle miles of travel
VOC	Volatile Organic Compound

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SUMMARY

The 1990 Clean Air Act Amendments require states with areas not meeting the national standards for air quality to prepare implementation plans for cleaning up the air. As part of the implementation plan, states prepare emission inventories which report the amount of pollution produced by industry, small businesses, and mobile (transportation-related) sources.

In order to calculate the mobile source portion of the emission inventory, transportation planners rely on computer models. Mobile source emissions estimates are produced for the emission inventory by multiplying an emission factor by a measured vehicle activity (such as vehicle miles of travel). The Environmental Protection Agency requires the use of their model, MOBILE, to produce emission factors to be used in all states except California. California uses its own emission factor model, EMFAC. Travel demand models, used for transportation planning, produce the needed vehicle activity data. Emissions modeling systems act as an interface between the emission factor models and travel demand models, pulling data from both models to calculate mobile source emissions estimates.

This report describes both emission factor models, including major inputs and outputs, and concerns that have been raised about the accuracy of their emission factors. The authors compared the two models and found the principal difference to be their treatment of trip end emissions. EMFAC treats evaporative and start-up effects as proportional to trip ends, while MOBILE treats trip ends as a part of its running emissions total. Research is being sponsored by both the EPA and California to try to increase the accuracy of their models.

This report describes nine emissions modeling systems, including their major inputs and outputs, and which emission factor model and travel demand models each emissions model will interface with. BURDEN and DTIM were written to work with EMFAC, and are therefore used only in California. Systems Applications International has modified DTIM to work with MOBILE. This version is called PC-DTIM and works with MinUTP or TRANPLAN. The following models all use MOBILE to obtain

emission factors. IMPACT is a model developed for use in Texas, and is the only MOBILE-based program that accounts for trip ends, but since MOBILE does not yet provide trip end emission factors, EPA has not yet approved the use of IMPACT. The Radian Corporation developed MoVEM as one module of a larger emissions estimation package used in the Lake Michigan Ozone Study. MoVEM does not interface directly with any travel demand models, but it can read travel data from an ASCII file. PERF was developed by the North Central Texas Council of Governments. One of the three modules that comprise PERF is used as an emissions model. PERF interfaces directly with TRANPLAN or with the Dallas-Fort Worth regional transportation model. The PREPIN/POLFAC/IMP SUM/SUMALL package was developed by the Texas Transportation Institute for use in Texas. Parts of the program are similar to IMPACT, but it does not split out trip ends as IMPACT does. The package reads data from the Texas Large Network Package, and has been used in several areas in Texas. PPAQ is an emissions model developed for New Jersey, and it interfaces with that state's transportation network models. TRFCNV is another emissions model developed by Systems Applications International. It has since been combined into their PC-DTIM model.

After evaluating the various models available, the authors conclude that none of the emissions models offer significant advantages in features, accuracy, or ease of use over the PREPIN/POLFAC/IMP SUM/SUMALL package currently being used in Texas.

CHAPTER I

INTRODUCTION

Over the past few decades, Americans and the world population in general have become increasingly concerned with the harmful effects of air pollution. Studies have found that air pollution can cause lung damage, nausea, chest pains, disorientation, and can negatively affect a person's internal defense systems toward foreign bodies. The groups found to be at greatest risk are children, the elderly, pregnant women, and people with respiratory problems or other infirmities. Air pollution can also damage plant life, animals, and man-made materials.

Due to this concern, Congress passed the Clean Air Act and several amendments to that act. The latest and most profound changes to the act occurred in 1990 with the passage of the Clean Air Act Amendments (CAAA). These amendments were designed to address acid rain, urban air pollution, and toxic air emissions, among other things. The amendments are long and complex, containing 175 regulations in 11 Title sections.

The CAAA reaffirm the federal government's requirement that all states meet the National Ambient Air Quality Standards (NAAQS). These are standards for acceptable pollution concentrations for six pollutants known to be harmful. Measured pollutant concentrations below the standards are deemed safe for humans. Concentrations above the standards are considered harmful. At the time the CAAA were being passed, the Environmental Protection Agency (EPA) estimated that 130 million Americans live in areas that do not meet the standards (1). The CAAA require states to implement plans to achieve attainment of the standards within specified lengths of time or lose federal funding of some projects. Areas more polluted have a longer time period in which to comply.

Ozone (smog), carbon monoxide (CO), and particulate matter (PM-10) are among the most prevalent pollutants. Lead, sulfur dioxide (SO₂), and nitrogen dioxide (NO₂) are others. Pollutants are measured by mass of pollutant per volume of air, usually in terms of parts per million (ppm) or micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). For instance,

the acceptable standard for CO is 9 parts of pollutant per million parts of air. Due to the variable nature of pollutant concentrations, standards also include a time period for measurement. The standard of 9 ppm for CO is valid only if tested over an 8-hour period. The standard for ozone concentrations is 0.12 ppm over a 1-hour average.

Sources of pollutant emissions may be classified into two broad areas: point and area. A point source is a large, unmoving source whose emission rate is significant as a singular generator. Area sources are a collection of small, geographically dispersed emitters that are not emitting pollutants at rates that are individually significant, but they are significant when taken as a group (2). Area sources include dry cleaners, gasoline stations, photo developers, etc. Mobile sources (vehicles) are considered a subset of area sources, but are valued separately for modeling purposes. Vehicles do not emit a lot of pollutants individually, but collectively they may account for 50 percent or more of the hydrocarbon (HC) pollution (one of the precursors to ozone) and 90 percent or more of CO (3).

As part of the air quality implementation plan, states must prepare emission inventories of specified pollutants for each nonattainment area within their state. For example, an emission inventory of CO, measured in pounds of pollutant per day, will be prepared for each area that does not meet the NAAQS for CO. Ozone is a secondary pollutant, meaning it is not emitted directly but is formed by a combination of chemicals in the air. Because ozone emissions cannot be directly measured, the emissions of the chemicals that form ozone, HC and nitrous oxides (NO_x), are estimated for ozone emission inventories. (HCs are also referred to as volatile organic compounds, or VOCs.) States develop emission inventories by estimating an emission rate (in grams per unit of activity) that pollutants are being emitted from the various kinds of sources and multiplying that rate by the activity measure to estimate the total amount of pollutant concentration the area will have over a given day. For mobile sources, the emission rates are produced by a computer model developed by the EPA, and the activity measure of interest is the aggregate miles of travel over the area being studied.

Mobile source emissions cannot be measured directly because of their nature, so computer models are used to estimate emissions from these sources. Modeled emission

estimates are used to create the mobile source portion of the emission inventories for CO and the precursors of ozone (HC and NO_x). Emissions models take activity data from traditional travel demand models and apply rates from an emission factor model to produce emission estimates.

In addition to the air quality implementation requirements, modeled emission estimates are also used for analysis of transportation plans. Part of the CAAA require that federally-funded transportation plans, programs, and projects conform to the attainment plans specified in the air quality State Implementation Plan (SIP). The emissions models enable planners to be sure that new projects will not interfere with air quality attainment goals.

Another benefit derived from emissions models is the data needed for input into the Urban Airshed Model (UAM), a computer model developed by the EPA to estimate regional ozone concentrations. The UAM requires input data of spatially gridded emission estimates. Some emissions models are able to produce the gridded output needed by the UAM while others produce output that can be run through the UAM's Emission Preprocessor System to produce gridded input for the UAM.

This report will describe several of the existing emissions models used in various states including Texas and will identify modeling practices that merit consideration in Texas. Background information on the two accepted emission factor models will also be provided.

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CHAPTER II

MOBILE SOURCE EMISSION FACTOR MODELS

INTRODUCTION

Mobile source emissions factor models aid in the preparation of emission inventories by providing an estimate of the rate of emissions for an average vehicle under average conditions. These models calculate the grams of HC, CO, and NO_x per vehicle mile. This provides an emission factor in grams per mile which can be used with an estimate of vehicle miles of travel (VMT), supplied by a travel demand model, to calculate total emissions. Multiplying the emission factor (g/mile) by the VMT per day produces the number of grams of pollutant emitted per day:

$$\text{Emissions} = \text{emission factor} \times \text{VMT}$$

The emissions are then used in the inventories required by the CAAA to determine progress toward attainment of the NAAQS or reductions in individual pollutants. The emissions per day figures are also used as inputs for the UAM which is used to estimate regional ozone concentrations.

Currently, there are two standard mobile source emission factor models: MOBILE and EMFAC. As of this writing, the current version of EPA's model is MOBILE5a. The next update, MOBILE6, is expected in the latter part of 1996. The EPA's model is required for use in all states required to produce emission inventories except California. Because California has different emissions analyses requirements due to their stricter emissions control laws, the EPA has approved their use of EMFAC, a model developed by that state. The current version of California's model is EMFAC7F.

MOBILE

MOBILE calculates the emission factors for eight different vehicle types and two regions, low- or high-altitude, for the three pollutants associated with mobile sources

(HC, CO, and NO_x). The eight vehicle types recognized by MOBILE are:

- (1) Light-duty gasoline vehicles
- (2) Light-duty trucks weighing up to 6,000 lbs. gross vehicle weight
- (3) Light-duty trucks weighing 6,001-8500 lbs. gross vehicle weight
- (4) Light-duty diesel vehicles
- (5) Light-duty diesel trucks
- (6) Heavy-duty gasoline vehicles
- (7) Heavy-duty diesel vehicles
- (8) Motorcycles

MOBILE treats all similar vehicle types for any given model year the same--it does not consider different makes or models or the owner's maintenance or driving habits--thus simplifying the calculations. Users may input values for some variables or use defaults supplied by the model; however, users must input values for certain local variables. MOBILE can estimate emission factors for any given year from 1960 to 2020.

The emission factors produced by MOBILE are used in preparing base year emission inventories and also for preparing future year emission inventory projections. It derives its emission factors by multiplying a basic emissions rate (BER) by a series of correction factors that account for variables (e.g., ambient temperature). The BERs are internal to the MOBILE program. Although different values for the BERs could be input by the user, EPA requires that the default federal standards be used. The correction factors are calculated using data that have been input by the user or left as default values (4).

The basic emission rates are derived from equations that figure emission rates for each vehicle type by pollutant and model year. In addition, the different emission standards and emission control technologies for different model years is taken into account. Furthermore, the BER equations account for different emission rates based on assumptions about mileage accumulation and deterioration rates (e.g., the deterioration rate of emissions increases after 80,500 kilometers (50,000 miles) for light-duty gasoline vehicles). The values for the BERs are supplied by emissions tests performed by vehicle manufacturers according to a standard procedure, the Federal Test Procedure (FTP).

FTP emission tests are performed on new vehicles while still at the manufacturer's plant. These tests measure both exhaust and evaporative emissions. For exhaust emission requirements, a vehicle is driven through a series of driving modes on a chassis dynamometer. The test lasts 23 minutes, averaging a vehicle speed of 31.6 kilometers per hour (19.6 miles per hour), and tests for CO, HC, and NOx. Emissions are measured for three different categories of exhaust: (1) cold transient (starting a vehicle with the engine cold), (2) hot stabilized (driving), and (3) hot transient (starting a vehicle with the engine hot). The fuel system emits HCs in the form of evaporation, both while the engine is running and after the engine is turned off. The period of evaporative emissions after the engine is turned off is called the hot soak period. Diurnal emissions are HC evaporations from the fuel tank, whether or not the vehicle has been operated. The FTP adds the hot soak and diurnal emissions to get the total evaporative emissions (2).

MOBILE may be operated in a variety of ways. For instance, it may prompt the user for data or use default values; it may give output data for visual inspection or data ready for input into another model.

The input data set consists of three sections: the Control section, the One-time data section, and the Scenario section. The Control section controls the input, output, and execution of the program. This section allows the user to require prompts or use default values. The One-time data section allows the user to change the default values for all scenarios for a given run of the program; however, the internal default values remain and will be available for later runs of the program. Default values the user may wish to change include annual mileage accumulation rates or registration distributions by age for each vehicle type. The Scenario section allows the user to set up specific situations for which the model will calculate emission factors. In this section, the user must specify such inputs as the calendar year of evaluation and the region (low- or high-altitude) (4). In addition, the user may supply values for optional variables in this section, which would be used only for the scenarios indicated by the user.

The user chooses the input variables by entering a value for the corresponding flag in the Control section. For instance, if the user wants to input a value for local

tampering rates in the One-time data section, a coded value (in this case, a "2") must be input in the tampering rates flag (TAMFLG) of the Control section. For Scenario section variables, the user must also input a code for the corresponding Control section flag (4). Several variables can be input in either the One-time data section or in the Scenario section, depending on the user's choice. If the user changes the variables in the One-time data section, the value of the variable will be used in all scenarios for a given run of the program. If the user changes the variables in the scenario section, the values will apply only to those scenarios for the given run. By inputting the appropriate values into the Control section flags, the user tells MOBILE where to look for the optional variables and how they will be used during a particular run.

The user may choose default values for most of the variables in the One-time data section. Some of the fields for which the user may or may not wish to enter values include:

- Tampering rates
- VMT mix
- Mileage accumulation rate by age
- Registration distribution by age
- Anti-tampering program information
- Inspection and maintenance program information
- Refueling vapor recovery system descriptive records
- Trip length distribution
- Model year inclusion vector record

The local area parameter (LAP) record and the scenario record together provide local information for a particular run of MOBILE. A LAP record must be included at least once in every run of the program. Users may choose one LAP record for each scenario of the run (by including LAP records in the Scenario section) or one LAP record for all scenarios of the run (by including it in the One-time data section). The EPA generally recommends using the same LAP record for all scenarios of the run.

The LAP record consists of seven mandatory and three optional input variables. The seven required fields are:

- (1) Scenario name
- (2) Gasoline volatility class
- (3) Minimum daily temperature
- (4) Maximum daily temperature
- (5) Base (pre-control) Reid vapor pressure (RVP)
- (6) In-use (controlled) RVP
- (7) In-use RVP start year

The three optional fields are:

- (1) Oxygenated fuel
- (2) Diesel sales fractions
- (3) Reformulated gasoline

The Scenario section allows the user to model emission factors for one or several scenarios per run, and it contains one to ten records per scenario. The only required record for each scenario is the scenario descriptive record which contains these required variables:

- (1) Region
- (2) Calendar year of evaluation
- (3) Average speed(s)
- (4) Ambient temperature
- (5) Operating mode fractions
- (6) Month of evaluation (January or July)

The scenario descriptive record may include one or more optional variables, such as:

- Low-emitting vehicle parameter record
- VMT mix by vehicle type
- Trip length distribution (measured in time, not distance)
- Additional correction factors for light-duty vehicles (such as air conditioning use)

The three categories of output from MOBILE are prompting messages, diagnostic messages, and formatted reports. Prompting messages are simply the prompts to allow the user to input data for variables. Diagnostic messages concern user-supplied data and

are displayed as errors, warnings, or comments. MOBILE displays warning messages if an operation occurs that was not necessarily intended by the user but was caused by user input. Comments, a type of warning message, are supplied for the user's information. MOBILE will stop a program run and display an error message when invalid data have been entered. Warnings and comments are less serious than errors and will not stop a run (4).

Reports are available in six formats. The user chooses a format by entering a coded value in the appropriate flag in the Control section. Two of the report formats will produce numeric output for use as an input file for another computer model. Formats three and four will print out reports for visual inspection. The fifth format will print a report for visual inspection along with detailed tables of model year emission factor information. And the sixth format option provides data in the form of a spreadsheet. The reports contain information on the altitude, ambient temperature, average speed, operating mode, etc.

Currently, several variations of MOBILE are being used. One variation was written to model emissions in Juarez, Mexico. Another was written to model Tier 2 tailpipe standards, in the event that some states decide to opt for higher vehicle standards earlier than required. Macintosh and PC Windows variations to MOBILE are available.

Expected revisions to MOBILE include accounting for command enrichment episodes. These are episodes such as cruising at 64.4 kph (40 mph) and then suddenly accelerating to pass another vehicle. Some studies show MOBILE to be under-predicting HC by about 10 percent for these command enrichment episodes. EPA expects that it will be somewhat difficult to correct for this because command enrichment only occurs in about one percent of all driving, making real-world measurements difficult. Another, similar type of driving behavior that may not be adequately covered by MOBILE is panic stops which may cause deep spikes in emissions. EPA does not know how to measure this or account for it right now. Another incident they need to account for is speeds over 104.6 kph (65 mph). Real-world tests have shown that a fair number of drivers travel at speeds above 104.6 kph

(65 mph). EPA believes the new evaporative test procedure will have perhaps the largest effect on MOBILE (5).

EPA will perform tests during 1994 for a MOBILE revision. In 1995, they will analyze the data gathered in 1994. In early 1996, they'll begin revisions to MOBILE and will release MOBILE6 sometime later in the year (5).

EMFAC

EMFAC was developed by the California Air Resources Board (CARB) and the California Department of Transportation (Caltrans), for use as the emission factor model in their state. California is allowed to use this program instead of MOBILE for its emission inventories because the state has stricter environmental standards than the national average and EMFAC produces slightly different results. It is a macroscale computer program that generates composite emission factors for exhaust and evaporative emissions of HC, CO, and NO_x in grams per hour (g/hr). It can also estimate emissions for particulate matter from tire wear or exhaust (in g/hr), and it can estimate fuel economy (in gallons per mile). It is used with companion programs to produce emission rates that are proportional to trip ends.

Two of EMFAC's companion programs, the California I/M Emission Factor (CALIMFAC) and E7FWT (called the Weight Program), provide input to EMFAC. CALIMFAC provides basic emission rates to EMFAC from the FTP rates used by EPA and from surveillance and testing done in California. EMFAC adjusts these FTP-based emission rates to non-FTP driving conditions using a series of correction factors (such as speed, temperature, etc.). The Weight Program provides EMFAC with estimates of vehicle mileage accumulation and with weighted fractions of vehicle activity (VMT, number of trips, or vehicle population) by model year.

EMFAC is made up of program controls (input) and output header records (output). All of the fields in the program control records, and all of the records themselves, are optional. Default values are available for all records, and the records may be input in any order. Some of the input control records are:

- Title

- Global parameters
- Vehicle category
- Extra load and trailer towing
- Species selection
- Speeds
- Dewpoints
- Start ambient temperatures
- Running ambient temperatures

The global parameter record consists of many of the same fields that are required input in MOBILE such as calendar year, altitude, speeds, and temperatures. In addition, this record includes fields for discomfort index bounds, number of dewpoints, and temperature/dewpoint combinations for running impacts (6).

EMFAC takes data from three control records and uses it to construct two temperature/dewpoint combinations. One of the sets is used for start emission rates, and the other is used for running emission rates. The running emission rates are normally adjusted for both speed and temperature, but start rates are usually not adjusted in this manner. Another reason to separate the running and start rates by temperature/dewpoint combinations is that cold start emission rates are much more sensitive than running rates to temperature. The dewpoint is important because it supplies a measure of humidity, which affects the air conditioning use factor and the NOx humidity factor (6).

EMFAC can produce output in a format for visual inspection. The output produced consists of composite impact (emission) rate records for several vehicle classes, technologies and impact producing processes, and many operating conditions. Running rates are sensitive to dewpoint, ambient temperature, and speed (6).

The emission factors produced by EMFAC are fed into one of two emissions modeling systems, depending on the final output required. For emission inventories, the rates are fed into BURDEN, an emissions model used by CARB to produce regional inventories. If gridded output is desired for use later with the UAM, the IRS (Impact Rate Summarization) and DTIM (Direct Travel Impact Model) programs are used with

EMFAC. Both BURDEN and DTIM will be discussed in the next chapter of this report.

IRS is the program used to process EMFAC's emission rates for DTIM. If the EMFAC user were to specify maximum values for the input variables, EMFAC could produce more than a million output records (6). Due to the tremendous amount of rates reported, IRS is used to summarize the rates over vehicle class and technology, thus producing fleet rates. IRS can then print the composite fleet rates or write them to a file for further processing by DTIM (7).

Although the EPA introduced the concepts of cold and hot start and hot soak emission effects, the California set of programs extend that concept by treating start and soak impacts as "proportional to trip ends rather than as an adjustment to running impact rates" (8). This approach provides better spatial-temporal resolution of emissions and makes the start and soak parameters more stable between regions (8).

COMPARISON OF THE EPA AND CALIFORNIA MODELS

Both MOBILE and EMFAC models lack data on emission rates outside of FTP conditions and on vehicles other than the light-duty vehicle class. In addition, both models have limited data on the emission characteristics of high-mileage vehicles (9).

The principal difference between the two emission factor programs is their treatment of "trip ends". EMFAC treats evaporative and start-up effects as proportional to trip ends, and it treats running emissions as proportional to VMT. MOBILE treats trip ends as a part of its running emissions total. MOBILE provides separate emission factors for evaporative emissions but not for cold and hot start emissions. MOBILE expresses all rates in grams per mile units. EMFAC expresses running rates in grams per hour units, and evaporative rates in grams per mile (running loss), grams per trip (hot soak), and grams per vehicle per day (diurnal).

MOBILE could be modified to break out trip end effects from running emissions. Treating trip end effects separately allows for a more accurate determination and spatial representation of evaporative and start-up emissions. By converting to per hour impact rates, California's EMFAC has extended the limits of MOBILE's speed factors at both high and low speeds. EMFAC takes advantage of the stability of time-based speed

factors at low speed to fill in the gap between idle and 8 kph (5 mph) by linear interpolation. IRS is able to handle the high speeds by assuming that per mile rates are constant over 88.5 kph (55 mph).

There are several other differences between the two models. Both models treat the flex point of emissions differently. The flex point is that mileage accumulation point where the deterioration rate of emissions changes. For MOBILE that point is 80,500 kilometers (50,000 miles) for all vehicles and pollutants, and the deterioration rate increases after that point. For EMFAC the flex point is different for different model years and pollutants, and the deterioration rate usually decreases after that point. In addition, MOBILE is more sensitive than EMFAC to changes in mileage accumulation rates (9). Other differences include the following:

	MOBILE	EMFAC
Calendar years covered	1960-2020	1970-2010
Number of model years	25	35
Pollutants	HC, CO, NO _x	HC, CO, NO _x , PM
Number of vehicle types	8	13

For the vehicle types, EMFAC breaks them down further into technology types, such as catalyst or non-catalyst; and it includes diesel as a technology type. In addition to the extra pollutant modeled by EMFAC, it can also produce estimates of fuel economy. For fleet distributions, EMFAC uses California-specific data while MOBILE uses national data. However, MOBILE does allow the user to input area-specific distribution data. Neither model does a very good job of estimating emissions from older vehicles, but EMFAC does the better job of representing them in the fleet (9).

Both models are able to estimate emission rates, but there are concerns about the accuracy of those estimates.

CONCERNS WITH CURRENT EMISSION FACTOR MODELS

In order to accurately assess the air quality problems of a region and whether or not progress is being made in pollution reduction, reliable emission inventories are a necessity. Because mobile source emissions are measured through modeling, the accuracy of the emission factor model is crucial to the accuracy of the emission inventory. There has been concern due to studies claiming that neither EMFAC nor MOBILE has a high degree of accuracy.

In studies performed in the late 1980s, researchers took samples of actual mobile source emissions from several on-road and tunnel sites and then compared the results with emission estimates produced by modeling. One of the most well-known of these studies, popularly known as the "Van Nuys tunnel study," found the California model to be underestimating HC and CO emissions by as much as 280 percent and 170 percent respectively. Because the California model was based in part on EPA's MOBILE model, the EPA model's accuracy was called into question as well (10).

The EPA gets its estimates of average emission rates for vehicle types and model years from the Federal Test Procedure performed on new vehicles while still at the manufacturer's plant and from the Emission Factor Program which performs emission tests on light-duty vehicles and light-duty trucks from the in-use fleet (10). These vehicles are borrowed from private owners who are randomly selected. The Emission Factor Program performs the same test procedures as the FTPs used on new vehicles. These tests result in emissions data for both new and in-use vehicles; however, the tests used cannot account for the varied operating conditions of in-use vehicles such as the acceleration rate used by different drivers and the kind of fuel used. To compensate, the EPA performs tests using different speeds, temperatures, and fuels from those used in FTP testing. Even so, the emission factor models can only estimate average emissions for different types of vehicles under average conditions (10).

In addition, the data collected from the in-use vehicles may not truly represent the in-use fleet. Very old vehicles and those with unusually high mileage accumulation are not adequately represented in the data used by both the EPA and California (10). Vehicles chosen for Emission Factor Program testing are subject to voluntary

participation from the owners. This may lead to an underestimation of high and super-emitting vehicles, since owners of such vehicles may not be willing to participate in the testing due to embarrassment over poor vehicle maintenance (10). The EPA cannot test all vehicles under all possible conditions, so they must extrapolate data from their known samples. The EPA admits that "biases introduced by these limitations are likely to be in the direction of underestimating emissions" (11).

The degree of emission underestimation is lessening with the newer models. When the tunnel study calculations were performed again using a newer version of MOBILE, the discrepancies between measured and modeled emission estimates dropped to 70 percent for HC and 90 percent for CO. The EPA points out that both their and California's models were designed to estimate average emissions over a broad geographic region and longer time periods than those used in the tunnel study. Because of this, the tunnel study and studies similar to it should not be viewed as model validation tests. However, the EPA concedes that these studies did raise legitimate questions concerning the accuracy of the models (10).

FUTURE MODEL IMPROVEMENTS

EPA, CARB, and Caltrans have ongoing research programs directed toward the continued improvement of the MOBILE and EMFAC emission rate models. Since passage of the CAAA, research on mobile source emission rates has grown significantly. CARB and Caltrans are conducting research in the following areas:

- Vehicle mileage accrual rates
- Vehicle population age distribution
- Number of starts per vehicle per day by vehicle age
- Vehicle cold/hot start trip fractions/continuous start function
- Vehicle speed distributions
- Speed correction factors
- Alternative driving cycles
- Off-cycle driving
- High emitting vehicle rates

- Modal acceleration testing
- Evaporative running loss emissions quantification

EPA is conducting research in the following areas:

- Federal Test Procedure review
- Emission rate database update for all sources
- Mobile source modeling using modal data

In time, the results of this research will be incorporated into MOBILE and EMFAC and the accuracy and sensitivity of these mobile source emission rate models will be improved. The accuracy of the traffic data that is used in conjunction with the emission rate models will also have to be improved.

Texas will continue to use the MOBILE model to estimate emission rates for two fundamental reasons: the state is required by EPA to use MOBILE for all regulatory applications associated with the CAAA, and the emission rates produced by the EMFAC model are applicable only to vehicles manufactured to California standards.

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CHAPTER III

EMISSIONS MODELING SYSTEMS

INTRODUCTION

Emissions modeling systems are computer programs that retrieve information from both emission factor and travel demand models to produce mobile source emission estimates. While MOBILE and EMFAC compute emission factors, travel demand models produce VMT, speeds for the links within the zones of the area being surveyed, and information about the number of trips for each zone.

A very simple example would show an emissions model multiplying the VMT from the travel demand model by the emission factors from MOBILE to produce an estimate of emissions. But the emissions models do more than that. Whereas MOBILE can produce emission factors for average vehicle types at average speeds, an emissions model can use information gained from the travel demand model, along with the emission factors from MOBILE, to produce emission factors for speeds and vehicle types associated with a particular zone within a modeling area. These area-specific calculations allow the user to more closely estimate actual emissions for a particular area. Emissions models can also be used to forecast future emission estimates.

Emissions models may produce emission estimates in a regional or a gridded output format. Several models are capable of producing both kinds of output. The regional emission estimates, which could be countywide, zonal, or some other size, are used in preparing emission inventories. Gridded emission estimates, in which emissions are assigned to horizontal grid cells, are used as input to the UAM, a photochemical air quality simulation model. This chapter will give a brief description of several of the emissions models in use today.

For those models not equipped to provide gridded output, modelers may wish to use the EPA's Emission Preprocessor System (EPS). This is a set of six FORTRAN programs that must be executed sequentially, drawing data from files created prior to running the EPS system. The six EPS programs take low-level point, area, and mobile

source emission estimates and reallocate the regional estimates to grid cells in a format which can be input to the UAM.

BURDEN

BURDEN is an emissions model developed for use with EMFAC in California. BURDEN calculates emission estimates in tons per day and prints out a report detailing the total emissions for each pollutant for a specific inventory year. Its two primary functions are to: (1) read activity factors from data files and multiply by EMFAC's emission factors, and (2) sum and print out on-road mobile source emissions estimates for each of the 13 vehicle-technology types recognized by California, each major process (such as hot soak evaporative emissions), each pollutant, and each modeling region (usually a county).

The current version is BURDEN7F, which can be used for annual average inventories or for seasonal ("planning") inventories. The required input and the output produced for each kind of inventory run are different enough that CARB considers each kind of run, either planning or annual average inventory, to be performed by different versions of BURDEN, even though both runs use the same basic system.

Average annual inventories, based on an ambient temperature of 24°C (75°F), have been available for any inventory year from 1970-2010. However, changes in RVP and oxygenates in gasoline, as required by Phase 1 and Phase 2 of the Reformulated Gasoline program recently adopted, have limited BURDEN's ability to forecast inventories. CARB is currently developing new weighted average factors to compensate for the new requirements (12).

Planning inventories cover ambient temperatures from -1 to 43°C (30 to 110°F), whereas the annual inventories are based on an average temperature of 24°C (75°F). In addition, planning inventories divide a 24-hour period into six periods of varying lengths. BURDEN can model different ambient temperatures, levels of vehicle activity, and speed distributions for each of the six time periods. These estimates for the six periods are then summed for each appropriate vehicle class, technology group, process, and emission type (such as exhaust, evaporative, etc.), thus producing estimates for the

whole planning day. Planning inventories are reported by county and, when appropriate, by air basin. When air basins contain two or more counties, BURDEN calculates inventories on a subcounty basis (12).

BURDEN is used with three other programs: CALIMFAC, E7FWT, and EMFAC. CALIMFAC calculates base emission rates for both Inspection and Maintenance (I/M) program and non-I/M program conditions. The results are fed into EMFAC. E7FWT, the Weight Program, calculates activity fractions of the 13 vehicle-technology types for each inventory year. The 13 vehicle-technology types recognized by California are:

- | | |
|------------------------------------|-------------------------------------|
| (1) Light-duty auto, catalyst | (7) Medium-duty truck, catalyst |
| (2) Light-duty auto, non-catalyst | (8) Medium-duty truck, non-catalyst |
| (3) Light-duty auto, diesel | (9) Heavy-duty truck, catalyst |
| (4) Light-duty truck, catalyst | (10) Heavy-duty truck, non-catalyst |
| (5) Light-duty truck, non-catalyst | (11) Heavy-duty truck, diesel |
| (6) Light-duty truck, diesel | (12) Urban bus, diesel |
| | (13) Motorcycle, non-catalyst |

The results from E7FWT are also fed into EMFAC. EMFAC then calculates emission factors by pollutant, process, and vehicle-technology type for a given calendar year. These emission factors are then read by BURDEN.

BURDEN reads the emission factors from EMFAC and vehicle activity data from various sources, such as Caltrans or the California Department of Motor Vehicles. Vehicle activity data include VMT, vehicle populations, trips taken (while distinguishing between hot and cold starts), speed distributions, and ambient temperature data. Some of the activity data must be refined or modified in some way by staff before being input to BURDEN (12).

BURDEN requires the following three kinds of input files:

- (1) User input file. This file contains the date of the inventory year, which air basin is being modeled, the kind of output desired, and other data. The types of pollutants, percentages of catalytic and non-catalytic cold starts, and output requested for the six time-periods may be input by the user

when performing a planning inventory run.

- (2) Emission factor file from EMFAC.
- (3) County-specific input data. This file contains information on vehicle activity, speed distribution, temperature, air basin/county data, and others. The data required changes somewhat dependent upon whether an average or planning inventory is being run. For instance, four temperature data files are needed for a planning inventory run, whereas no temperature is required for the average inventory run since it assumes a temperature of 24°C (75°F) (12).

BURDEN produces emission estimates for counties and air basins and lists them in alphabetical order by air basin and then by counties within each air basin. For planning inventories, the output will be limited to only those counties in nonattainment for the pollutant specified by the user. For average inventories, the output will list emission estimates for any or all of the air basins according to the user's input data. Statewide emission estimates can be produced when requesting output for all air basins in an average inventory run (12).

BURDEN cannot produce the gridded output required for UAM modeling. When gridded output is needed, California uses the DTIM emissions model.

DTIM

DTIM, or the Direct Travel Impact Model, was developed for use with the EMFAC and IRS programs discussed earlier. Currently, there are two versions of DTIM. One is the mainframe program used with EMFAC in California. The second version has been split into two PC versions and modified by Systems Applications International (SAI) to be used with the EPA's MOBILE emission factor model or California's EMFAC model. These versions of DTIM are currently being used or tested in several cities within California and in other states.

The mainframe version of DTIM was written by Caltrans to produce the gridded output needed for UAM modeling that BURDEN cannot produce. DTIM reads trip assignment data from a Caltrans transportation model and emission rates from

EMFAC/IRS, and it produces emission estimates in gridded format.

The trip assignment data contains information on the number of trips originating or terminating within each zone. DTIM takes this information and calculates start and evaporative emission rates in proportion to the trip ends reported by the transportation model. In addition, DTIM multiplies the per hour running rates by the vehicle hours of travel (VHT) for each link (13).

DTIM also processes temperature information. It reads dewpoints and temperatures from EMFAC/IRS and can allocate the traffic volume to any hour of the day with a corresponding temperature. DTIM also allows the user to provide values for temperatures and dewpoints for each grid cell and hour of the day (13).

DTIM performs gridding by assigning both the link and zonal emission rates to user-defined grid cells. It assigns rates for zones to the grid cell containing the zone centroid, or rates may be assigned to overlapping grid cells if that option is chosen. DTIM assumes a link is a straight line between its nodes and automatically segments links into grid cells (13).

DTIM not only calculates the emissions from mobile sources, but it also calculates the fuel used by them. Fuel consumption is reported by grid cell and is used in planning analysis (8).

User inputs to the DTIM program are called "program control records," and each record may contain several fields. All of the program control records are optional; DTIM provides default values for all fields. Some of the records are:

- (1) Title
- (2) Global parameters: containing fields for the year, altitude, speed adjustment for hot stabilized running rates, and EPA air condition use limits
- (3) Vehicle class
- (4) Species selection
- (5) Speeds: idle through 112.7 kph (70 mph) in 8 kph (5 mph) increments
- (6) Dewpoints: 13 values ranging from -18 to 16°C (0 to 90°F)
- (7) Start ambient temperatures: -18 to 16°C in 2.7° increments (0-60°F in 5°

increments); 17 temperature values over 16°C (60°F)

- (8) Running ambient temperatures: -18 to 16°C in 5.4° increments (0 to 60°F in 10° increments); 18 temperature values over 16°C (60°F) (8).

DTIM produces two kinds of output files of gridded emissions: one is for UAM modeling and the other is for planning analysis. The modeling file will usually have hourly resolution and will have HCs grouped by reactivity. The planning file will usually have less temporal resolution, and it reports travel (including cold starts and hot soaks) and fuel consumption by grid cell and output table. It also outputs a file containing zonal and link emission rates. The zonal rates refer to both trip end and intrazonal rates, while the link rates refer to running emission rates. By treating trip ends proportionally to cold start and hot soak emissions, DTIM produces better spatial and temporal resolution of mobile source emissions (8).

PC-DTIM

The PC version of DTIM, called PC-DTIM, calculates link level, hourly emission rates from information output by transportation models and from EMFAC. SAI has already developed a version to be used with EMFAC, and they are developing a version to be used with MOBILE for cities outside of California; however, documentation on the MOBILE version of PC-DTIM was unavailable.

The two PC versions of DTIM have been used in several cities. Sacramento, Fresno, and Riverside have used the EMFAC version; while Louisville, and possibly Denver and Provo, have used the MOBILE version.

SAI has also developed a PC version of the IRS system to be used with PC-DTIM to produce fleet average emission rates. Vehicle activity data are gathered from transportation models, such as MinUTP and TRANPLAN. To make their model more user-friendly, SAI developed menu systems for both PC-DTIM and PC-IRS, thus allowing inexperienced emissions modelers to effectively use the system.

While PC-DTIM and PC-IRS are the core programs of the system, a third program, PREIRS, is needed to reformat and sort emission rates from EMFAC for all vehicle classes. Together with the two user interface programs, IRSMENU and

DTIMMENU, these five programs make up the PC-DTIM emissions model system. "Of the five programs in the PC-DTIM system, four are used for the initial setup of PC-DTIM runs and would rarely need to be rerun once the system has been set up for a specific region and calendar year" (14).

PREIRS reads EMFAC emission rates from an ASCII file and modifies the rates to adjust for I/M programs, diurnal temperatures, and dewpoints. PREIRS produces an output ASCII file of emission rates which is then input to PC-IRS.

The IRSMENU program prompts the user for information and then prepares two files to be used by PC-IRS:

- (1) An options file which provides information on the fleet mix, the correspondence of technology to species, and the correspondence between technology and start emission rates, and
- (2) A system file which contains the names of all the files to be used by PC-IRS (e.g., the name of the emission rate file produced by PREIRS) (14).

Using the options, system, and emission rates files created by IRSMENU and PREIRS, PC-IRS summarizes the emission rates from EMFAC, which are stratified by vehicle class, into fleet average rates to be used by PC-DTIM.

Just as IRSMENU does for PC-IRS, DTIMMENU prepares an options and a system file to be used by PC-DTIM. These two files created by DTIMMENU are optional; PC-DTIM can use default versions of both files. User inputs to DTIMMENU include the following:

- Title
- Emissions (from PC-IRS)
- Temperature
- Starts, parks, and stables (the correspondence between these and the fleet rates)
- Trip type (the number of trip types and identifying labels)
- Cordon (minimum and maximum cordon nodes in the transportation network)
- Fleet (which fleet emission rates to use for each trip type)

- Parameter record
- Facility type (the number of facility types and identifying labels)
- Transportation model file format
- Speeds
- Outputs (user chooses among four types of files)
- PIOS (optional, Polygon Intersection and Overlay System file used for allocating trip end and intrazonal emissions to modeling grid cells)
- Region definition
- Coordinate translation (to translate coordinates from the transportation network into UTM coordinates for PC-DTIM)
- Units (to be entered if the transportation model's units of measurement do not match PC-DTIM's) (14)

PC-DTIM uses this information to multiply "fleet average emission rates by link and zone-specific estimates of travel activity (vehicle hours traveled (VHT) and trip ends) to predict total vehicle emissions (expressed in kilograms)" (14). PC-DTIM can produce daily or hourly emission estimates that can be gridded for input to the UAM. According to SAI, using PC-DTIM makes it possible to "assess (subject to the availability of appropriate data) the effect of changes in any of the four steps in travel demand modeling (trip generation, trip distribution, mode choice, and assignment) on mobile source emissions. Emission forecasts that are produced from travel demand model simulations are directly linked to the growth and development scenarios on which the travel forecasts are based" (14).

PC-DTIM requires a DOS operating system (DOS 5.0 or earlier) and a minimum of 10 megabytes of free disk space to run. Output files of modeling inventories (optional) typically require 30-50 megabytes of space.

IMPACT

IMPACT is an emissions model designed to be used with the EPA's MOBILE model. Design of the program was originally begun by the Urban Mass Transportation Administration (now the Federal Transit Administration) in 1981 but was never finished.

The Texas Transportation Institute (TTI) completed the program and has designed subsequent updates.

IMPACT is used in conjunction with the Texas Travel Demand Package, a transportation model used by the Texas Department of Transportation (TxDOT). Conversion programs developed for IMPACT reformat output from the Texas Large Network Assignment Models to the Urban Transportation Planning Study (UTPS) format used by IMPACT.

IMPACT computes total HC or nonmethane hydrocarbons (NMHC), CO, and NO_x for each traffic zone in the study area or for each grid in a user-specified grid square superimposed on the study area, thus producing both regional and gridded emissions estimates. It uses emission factors derived from MOBILE but applies these rates on a vehicle trip basis rather than the VMT basis traditionally used with MOBILE models (11).

This model accounts for trip end emissions by computing and assigning start-up emissions to the zone of trip origin. Hot soak emissions associated with the trip end are assigned to the zone of trip destination. Hot running emissions associated with the path of the trip are assigned on a VHT basis to the zones traversed during the trip. Diurnal emissions, which are independent of the trip, are assigned in proportion to the number of trip ends occurring within a zone (11). When using grids, the start-up and hot soak emissions are assigned to the grids containing the zone centroids for the trip starts and trip ends; the hot running emissions are assigned to the grids traversed; and diurnal emissions are assigned to the grid containing the zone centroid in proportion to the number of trip ends occurring in a zone (11).

IMPACT is written in FORTRAN and an assembly language and requires the following inputs:

- (1) &PARAM, &OPTION, &SELECT cards to set parameters such as study year, to set program options, and to request reports.
- (2) &TRAVEL cards to define the travel occurring during each user-specified time period for calculation of emissions during that time period. Only one time period is allowed.

- (3) &DATA cards to specify user-desired grid information.
- (4) A link Z-File containing link attribute values (LAVs) which provide the assigned volume, length, and speed of each link and the zone in which each link is located.
- (5) A node Z-File containing the x,y coordinate at each node.
- (6) A zonal Z-File containing LAVs of trip productions and attractions, intrazonal VHT, and (optionally) intrazonal speed for each zone.
- (7) Optionally an anti-tampering program (ATP) or an inspection/maintenance program I/M can be included.

Z Files are the conversion programs used to reformat the data into UTPS format.

IMPACT produces the following (optional) outputs:

- (1) Eight choices of printed reports. Among them are:
 - A. A table of VHT-related emission factors for each vehicle mix.
 - B. A table of start-up emission factors for each vehicle mix.
 - C. Miscellaneous emission factors including for each vehicle mix:
 - (1) diurnal HC emission factors,
 - (2) hot soak HC emission factors, and
 - (3) crankcase blow-by HC factors.
 - D. Total emissions of each selected pollutant at the zonal or grid square level for each time period.
- (2) A LAV for each selected pollutant providing total emissions of the pollutant at the zonal level. If IMPACT is run with grid squares, no new LAVs are saved.
- (3) A card-image output file of total emissions for each selected pollutant by grid square (11).

IMPACT has been modified to comply with American National Standards Institute (ANSI) FORTRAN 77 standards. However, the UTPS subroutines which are used by IMPACT do not conform to FORTRAN 77 standards. The UTPS subroutines will compile and execute satisfactorily using the FORTRAN 66 option of the FORTRAN 77 compiler. IMPACT will run satisfactorily on any computer that is presently

supporting UTPS (11).

This program is appropriate for analyzing an entire urban area or for major traffic corridor studies. IMPACT is not designed to be used for intersection analysis nor for specific highway projects. IMPACT can be used to assess the combined effect of a number of highway and transit projects completed over a 10- or 20-year planning horizon in conjunction with simultaneous changes in land use and trip-making characteristics (11).

The IMPACT model has not been approved by EPA for use in preparing mobile source emission inventories, nor has it been approved for conformity analysis or other regulatory applications pending a demonstration that total mobile source emissions produced by IMPACT are identical to those that would be produced by an application of MOBILE with appropriate VMT estimates. Because of IMPACT's dependence on the number of trips and trip end emission rates, such a demonstration is not feasible until trip end emission rates are provided by MOBILE. The application of MOBILE currently does not provide for any user input on the number of trips in the study area. Texas nonattainment areas are using the PREPIN/POLFAC/IMP SUM/SUMALL software instead of IMPACT. TTI will be testing, in conjunction with the state air agency, whether the UAM is sensitive to gridded emissions with and without trip end emissions broken out separately.

MoVEM

MoVEM (Motor Vehicle Emissions Model) was written as one module of a larger emissions modeling system called GEMAP (Geocoded Emissions Modeling and Projections). This system was developed by the Radian Corporation as part of the Lake Michigan Ozone Study (LMOS), and it is also being used in California as part of the San Joaquin Valley Air Quality Study/Atmospheric Utilities Signatures, Predictions and Experiments Regional Modeling Adaptation Project (SARMAP). GEMAP calculates emission estimates for point, area, mobile, and biogenic sources; however, the different modules comprising GEMAP may be used as separate programs. The modules that make up GEMAP consist of:

- A Point Source Model
- An Area Source Model
- A Crude Oil Storage Tank Model (for the SARMAP project only)
- MoVEM
- A Biogenic Source Model (BIOME)
- A Grid Definition Model
- A Speciation Model
- An Uncertainty Model
- A Projections Model (15)

MoVEM can be used alone to calculate mobile source emission estimates, and may be used in areas other than the two project sites. There are two versions of MoVEM: (1) a California version (CAL-MoVEM) to be used with EMFAC, and (2) a 49-state version to be used with MOBILE (16).

MoVEM works with MOBILE to produce gridded, hourly, speciated emission estimates. It can also produce regional emissions by summing the gridded emissions (16). Although MoVEM does not interface directly with any transportation models, it can read modified data from any of those models as an ASCII (American Standard Code for Information Interchange) file. MoVEM accepts a wide range of input data from these models. It can accommodate hourly link-level or daily statewide or countywide data (17). The primary vehicle activity data needed are VMT for a given road or region, the percentage of VMT for each vehicle class, and average speed for the road or region (18).

MoVEM itself is made up of four components:

- (1) The Activity Data Module converts the VMT and speed activity data into SAS® data sets. It also checks data format, outputting a list of invalid data for correction, and checks to be sure the speeds are within the valid range of the MOBILE model. Optional adjustments to speeds and temporal profiles can also be made at this stage.
- (2) The Spatial Data Module converts ASCII network data containing link coordinates into ARC/INFO® format. ARC/INFO® then grids the data

and extracts it as SAS® data sets.

- (3) The Emission Factor Generation Module creates a series of output data sets covering a range of speed and temperatures generated using data input from MOBILE.
- (4) The Emissions Estimation Module adjusts activity data to reflect the specific day being modeled. It combines this adjusted data with emission factors to calculate emission estimates (19).

Each module may contain one or more programs, and the four modules run independently of one another. All four modules do not have to be run for each episode day. The first three modules are needed to process spatial and activity data for each new location. After this, the Emissions Estimation Module can be run to calculate emission estimates for each episode day (18). MoVEM contains a user interface which allows the modeler to run the four modules from menus.

MoVEM produces two reports with each run and seven optional reports. The two standard reports provide data on daily non-diurnal (report number one) and diurnal (report number two) annual average VMT by state, county, area type, and facility type. The optional reports include data on daily emission estimates by pollutant, process, and technology type; on- and off-network VMT; and others (19).

MoVEM is a public-domain software that can be used with different modules to produce gridded or regional emission estimates, uncertainty emission estimates, and projected estimates, among others. The program is written in a flexible programming language, but the user must be familiar with all of the components and able to reprogram parts of it when needed in order to effectively use the system.

CAL-MoVEM, the version written for use with EMFAC, is still under development. The calculations used in emission estimation are similar to those written for DTIM. However, by writing the CAL-MoVEM in a menu-driven, modular form, its developers hope that it will be easier to use and modify than DTIM (20). At this time, it is unknown how CAL-MoVEM compares to PC-DTIM, which is also menu driven. Radian's stated goals in the development of CAL-MoVEM are to:

- Estimate gridded, hourly emissions by vehicle class, engine type (diesel

- or gasoline), and emission control type (catalyst or non-catalyst);
- Separate the calculation of interzonal, intrazonal, and trip end emissions;
- Use hourly vehicle activity data for links and traffic analysis zones;
- Output gridded, hourly emission estimates for speciation and input to a photochemical grid model (such as the UAM);
- Provide alternate output of regional (countywide), daily emissions;
- Provide an emissions projection capability;
- Ensure compatibility with currently available motor vehicle emission factor and vehicle activity input data;
- Reduce the input file structure relative to DTIM;
- Provide ease of modification and expandability to accommodate alternatively fueled vehicles and potential modal emissions modeling methodologies; and
- Provide easier reporting of results with graphical capability (20).

Since it will be used with EMFAC, CAL-MoVEM will be able to split out trip ends rather than treat them proportionally to VMT as MoVEM does.

PERF

PERF is a post traffic assignment reporting program. Developed by the North Central Texas Council of Governments (NCTCOG) for use in the Dallas-Fort Worth area, the program consists of three modules that can be run separately for specific reports or together to produce an overall performance report. One module calculates system performance, producing data on total VMT, total VHT, congestion delay, and traffic control delay, among others. Another module provides demographic summaries for the urban area. The environmental module acts as an emissions model, producing emission estimates and data on fuel consumption.

The environmental module of PERF reads vehicle activity data from a transportation model and emission factors from MOBILE and then calculates regional or zonal emissions estimates. PERF can be run on either a mainframe or a PC.

PERF interfaces directly with TRANPLAN or the Dallas-Fort Worth regional transportation model, reading the vehicle activity data such as VMT, link volume and capacity, and other information. The program could also read modified input produced by other transportation models.

Emission factors are calculated by MOBILE, which must be run prior to a PERF run. The rates can be entered into PERF only by changing the FORTRAN source code in PERF; the program cannot read the emission factors directly from MOBILE. Each change in variables, such as calendar year or temperature, requires a separate run of MOBILE. For each run, a programmer must go in and hard-code the emission factors into PERF. For this reason, only a user familiar with FORTRAN programming can operate PERF.

The module produces emission estimates by day or by peak period for each zone or region. By modifying the peak hour factors in the source code, different time periods can be reported such as hourly resolution of estimates. PERF also reports emissions by species of pollutant (i.e., VOC, CO, or NO_x), and it provides data on fuel consumption. PERF does not split out trip ends as part of its emission calculations. It also does not produce the gridded output needed for UAM modeling, but zonal output can be assigned to grids using a geographic information system (GIS) outside of PERF.

When used together, the three modules of PERF could give the user information on the system performance, demographics, and emission estimates for a particular zone. However, as an emissions model, PERF does not appear to be very adaptable outside of the source code. It does not allow the user to modify data within the emissions model as in other models. Any changes in variables must be made in the transportation model or in MOBILE before being input to PERF. In addition, PERF does not appear to be user-friendly since it requires a FORTRAN programmer for each run.

PREPIN/POLFAC/IMPSUM/SUMALL

Another emissions modeling system used in Texas is the PREPIN/POLFAC/IMPSUM/SUMALL system. This system was also developed by the Texas Transportation Institute, and has been used in El Paso, the Beaumont-Port Arthur area,

Victoria, and Austin. The POLFAC and IMPSUM programs have been used for modeling in Houston along with Houston's own 24-hour and time-of-day assignment models.

PREPIN processes a 24-hour assignment and prepares time-of-day assignments and speed estimates by link for input to IMPSUM. If time-of-day assignments are already available (as in Houston), PREPIN is not used. POLFAC is a program used to obtain emission rates using MOBILE and outputs a format readable by IMPSUM. IMPSUM applies the emission rates obtained from POLFAC and VMT mixes to the assignment results for an area to estimate the emissions by county.

PREPIN was developed for use in areas that do not have time-of-day assignments. It processes 24-hour assignments from the Texas Large Network Package to estimate VMT and speeds for a specific time period (e.g., morning or afternoon peak hour). PREPIN uses the peak speed model developed by the North Central Texas Council of Governments to estimate directional time-of-day speeds and directional congested speeds. PREPIN uses the following inputs:

- (1) 24-hour assignments
- (2) Factors to estimate the portion of VMT in the subject time period
- (3) Factors to estimate time-of-day capacities from the 24-hour capacities
- (4) Factors to adjust the VMT to correspond with Highway Performance Monitoring System estimates
- (5) Factors to adjust the VMT to reflect seasonal fluctuations
- (6) Factors to indicate the directional split for link volumes
- (7) Factors to estimate the freeflow speed from the 24-hour link speed
- (8) A table of equals associating zones to counties
- (9) A table of equals associating zones to area types (21)

These data are used to estimate the volume to capacity ratio for the subject time period and estimate the operational speed. PREPIN uses these data to prepare the link input to the IMPSUM program. The two link records produced by PREPIN contain directional VMT and speed estimates for each link.

POLFAC reads a set of MOBILE data cards with either one or two scenarios in

it. The program is set up to provide an option for getting emission factors from two different years and averaging them (an option that was needed in Houston). It runs MOBILE as a subroutine. If two MOBILE scenarios are run, POLFAC runs both scenarios and then averages the results of the two runs for each speed. POLFAC obtains emission factors for eight vehicle types and 63 speeds (i.e., 3-65 m.p.h.) for the three pollutants (VOC, CO, and NO_x). It outputs these emission factors to an ASCII file for input to IMPSUM. IMPSUM can then apply the emission factors to a 24-hour period or to a specific time of day.

IMPSUM takes information from these two programs and calculates emissions by county, by roadway type, and by vehicle type. IMPSUM can also report emissions by grid square and emission type or by grid square, emission type, and vehicle type. The limits of the program are eight counties, 21 roadway types, and eight vehicle types. The basic inputs to IMPSUM are:

- (1) Data specifying the number of counties in the region and their names
- (2) Names of the road types used in the study (used to summarize emission results)
- (3) VMT mix by county and road type
- (4) Emission factors from POLFAC by county
- (5) Specification of the units for reporting emissions (grams, pounds, or tons)
- (6) Abbreviated assignment results by link (county number, road type number, VMT on link, operational speed estimate, and link distance are required for each link) (22)
- (7) X,y coordinates (optional)
- (8) Grid square (optional)
- (9) Coordinates of southwest corner of gridded area (optional)

Using these data, IMPSUM computes the emissions for each link and accumulates them by county. It reports the emissions for each county and pollution type by both roadway type and vehicle type. IMPSUM can also accumulate emissions by grid square and vehicle type if x,y coordinates are input. IMPSUM reports emissions by grams, pounds, or tons.

SUMALL sums results from multiple IMPSUM runs, producing reports in the same kind of formats that IMPSUM produces. SUMALL also calculates diurnal HC emissions from diurnal rates per vehicle and total vehicles by vehicle type and county. The basic inputs to SUMALL are:

- (1) Data specifying the number of IMPSUM runs to sum
- (2) Data specifying the number of counties in the region and their names
- (3) Names of the road types used in the study (used to summarize emission results)
- (4) VMT mix by county and road type
- (5) Emission factors from POLFAC by county
- (6) Specification of units for reporting emissions (grams, pounds, or tons)
- (7) Diurnal rates and the number of vehicles by county
- (8) Binary data sets from IMPSUM (21)

SUMALL reports emissions by both roadway type and vehicle type for each pollutant.

PPAQ

An emissions model developed for the New Jersey Department of Transportation (NJDOT) is the Post Processor for Air Quality (PPAQ) system. It was designed by Garmen Associates to calculate mobile source emission factors for use in the State's SIP emission inventories. At the time this report was written, the model produced only regional emission estimates; but a new version, expected in the early 1990s, will produce gridded emission output as well. PPAQ is currently being used in New Jersey and Pennsylvania on a statewide basis. In addition, the model is being used in Nashville and parts of Indiana.

PPAQ provides the connection between the MOBILE emission factor model and NJDOT's transportation network models which estimate VMT and speeds, among other things. PPAQ converts the physical, operating, and traffic volume data from the network transportation models into a format that can be input to the MOBILE model (23).

With a travel forecast model producing 24-hour and/or peak hour traffic volume forecasts by link, PPAQ reads the information and other data and performs these tasks:

- (1) Splits the assigned 24-hour volume for each link into 24 one-hour volumes;
- (2) Calculates the volume to capacity ratio for the mid-block condition for each of the 24 one-hour periods;
- (3) Spreads the volumes in excess of a threshold volume to capacity ratio (typically 1.2) to the "shoulders" of the peak period and recalculates the volume to capacity ratios for the affected hours;
- (4) Calculates the delays that result on both the link and the intersection approach;
- (5) Accumulates VMT and VHT into a three-dimensional matrix by area, facility type groups, and time periods;
- (6) Creates a complete MOBILE input file by appending the Control and One-time data sections of the MOBILE input file to the scenario control records for each cell in the three-dimensional matrix and by computing the total VMT and volume-weighted average speed for the cell/scenario;
- (7) Executes a run of the MOBILE program; and
- (8) Reformats MOBILE output to be compatible with desktop printers, and, if indicated, the post-processor captures emission factors for the three pollutants--HC, CO, and NO_x--and multiplies them by VMT, then accumulates cell and study area total emission burdens (23).

PPAQ contains three programs--PPAQ1, PPAQ2, and PPAQ3--which are used in conjunction with MOBILE. The PPAQ1 program performs network analysis by reading input data files, developing 24 one-hour volumes for each link, calculating capacities and speeds, accumulating VMT and VHT tables, and producing a run control file for MOBILE. PPAQ2 is the output post-processor. It reformats MOBILE output and multiplies emission factors by VMT and VHT to produce emissions by area, facility type, and time of day. PPAQ3 is the interactive report generator. It accesses the exploded link data, the exploded VMT/VHT summaries, and the output emissions file. PPAQ3 provides full-screen displays and custom reports.

The PPAQ/MOBILE system requires five input files. These files are:

- (1) PPAQ/MOBILE Control File containing run control parameters needed

to execute PPAQ1, MOBILE, and PPAQ2.

- (2) MinUTP/TRANPLAN-Loaded Network data containing link data.
- (3) Zone:Area Equivalency File that provides equivalences for converting traffic zone numbers to other geographic entities such as municipality, district, county, or region.
- (4) 24:1-hour Pattern File wherein each record represents a particular combination of area, facility type, peaking pattern, and a percentage distribution of the 24-hour volume to each of the one-hour volumes.
- (5) Speed/Capacity Parameters file containing pre-calculated link (or mid-block) capacity and zero-volume speeds, by facility type, area type, and number of lanes (23).

One run of the PPAQ/MOBILE system may produce as many as six output files, some of which are optional. The output files are:

- (1) Reformatted MOBILE output.
- (2) Summary HC/CO/NOx Burden - emission factors are multiplied by VMT, and VHT, VMT, average speed, HC, CO, and NOx are then summarized for each scenario and in total.
- (3) Emissions Data File - for each of the eight vehicle types and for the total of all vehicles, PPAQ saves VMT, VHT, HC, CO, and NOx for each scenario input to MOBILE.
- (4) Exploded Link Data (optional) - saves intermediate link-specific data.
- (5) Exploded VMT/VHT Table - VMT and VHT are accumulated and indexed by facility type group, area, and hour.
- (6) VMT by Speed Range Tables (optional) - contains the distribution of speeds for each cell of the array (23).

PPAQ provides a linkage between a network-based transportation demand forecasting system and MOBILE. PPAQ is able to read a standard highway planning network, such as MinUTP or TRANPLAN, as its network input. It uses this network data to support capacity analysis, travel time calculations, and aggregation of average speeds by geographic area, time period, and facility type. It will convert 24-hour or peak

period traffic volumes into 24 one-hour volumes, if desired. Data on capacity and speed relationships contained in the *Highway Capacity Manual* are used to calculate travel speeds on each link for each of the 24 one-hour periods. VMT and VHT are accumulated, and average speeds are calculated. Using data prepared by PPAQ, MOBILE is run under the control of PPAQ. Finally, the MOBILE output is reformatted and total emissions burdens (based on VMT) are calculated (24).

TRFCONV

TRFCONV ("trafcon") is an emissions model developed by SAI to produce gridded emission estimates for input to the UAM. TRFCONV calculates hourly traffic volume and hourly vehicle speed for each link. Using data from MOBILE, TRFCONV determines a link-specific emission factor for each hour (25). This model has been used in Phoenix, Tucson, and Las Vegas.

TRFCONV requires five input files consisting of three user-defined input files and two data files. An additional file containing data on airport emissions may also be input as a data file. The three user-defined files are:

- (1) A user input file, which contains "user-specified variables for the specific modeling episode, including data and time range being modeled, specifications for the speed curve to be used, temperatures for each hour of the modeling episode, and cell coordinates for the specified subregion," (25)
- (2) An adjustment factor table, which contains "traffic adjustment and emissions factors, as well as hot/cold start percentages and capacity adjustment factors," (25)
- (3) And a UAM header file, which contains information, such as reference origin, grid cell sized, and other variables needed to define the modeling grid and parameters (25).

The two required data files contain link and node information for the transportation network being modeled. The link attribute value (LAV) data includes information on "24-hour traffic volumes, number of lanes, link lengths, facility and area

types, starting and ending nodes, and link node coordinate data" (25). Data from the loaded highway network file output by TRANPLAN must be converted, using the UTMNOD utility, into two files for input to TRFCONV. One file contains link attribute data, and the other contains node coordinate data (25).

TRFCONV produces two output files. One file outputs a printed report containing tables of input and output data. The other file is the binary emission data which is input to the UAM.

The printed report displays the following 16 tables:

- (1) User-selected inputs to TRFCONV
- (2) The highway speeds when the volume-to-capacity ratio is equal to zero
- (3) The speed by volume to capacity ratio for facility type
- (4) The hourly traffic adjustment factors by area and facility type
- (5) Hourly percentages of cold starts and hot starts
- (6) The cold/hot start regression coefficient factors by temperature, cold start factor, hot start factor, and intercept
- (7) The emission factors for HC for various speeds and temperatures (if species selected)
- (8) Emission factors for NO_x for various speeds and temperatures (if species selected)
- (9) Emission factors for CO for various speeds and temperatures (if species selected)
- (10) The capacity adjustment factors for the number of lanes by area and facility type
- (11) All airport emission inputs by date, hour, x cell, and y cell
- (12) Total emissions for user-specified species by grid cell for each hour (two pages per hour)
- (13) Total VMT by grid cell for each hour (three pages per hour)
- (14) Average speed by grid cell for each hour (two pages per hour)
- (15) Average speed and VMT for entire domain and the grand total of emissions for each species

- (16) The total sum for each species in subregions specified by the user (if specified) (25)

The binary emission file contains four header records and the gridded emissions data for each species. The header records contain the following information:

- File name, number of chemical species, and beginning and ending times and dates of the file
- The coordinates of the reference origin, location, and size of the modeling region, and the vertical description of grid cells
- The x and y locations of the segment origin with respect to the modeling region origin, as well as the number of grid cells in the segment (both the x and y directions)
- The names of the species being modeled (25)

TRFCONV models emission estimates for both the base year and future years. TRFCONV was designed to reflect changes in emissions over time and also changes resulting from the implementation of emission controls. Changes in the emission characteristics of individual vehicles can be simulated by altering the emission factor tables. Changes resulting from emission controls can be calculated using different LAVDATA files or applying traffic volume adjustment factors.

SUMMARY

The emissions models discussed above that use MOBILE for emission rates, with the exception of IMPACT, all use essentially spread sheet type calculations; an emission rate in grams per mile is multiplied by a VMT estimate. The emissions models differ in the degree of disaggregation in the emission rates produced and the travel model link data. The network link data with its assigned traffic volume provide the basic unit of analysis that is used to develop the link based emission estimate. The models differ in the way that the link data are disaggregated by time period, how average link operating speeds are estimated, how VMT mix fractions are handled, etc. The models also differ somewhat in the way that speed, temperature, VMT mix, etc., values are input into MOBILE for the calculation of emission rates. The manner in which the software

interfaces between the travel models and the emission rates estimates also differs. But fundamentally these emissions models are similar and would probably produce similar regional emission estimates if applied to the same geographical region. The reasons for selecting one emissions model over another have more to do with software application and user operational considerations than with the accuracy of the emission estimates produced.

This study did not find any emissions model based on MOBILE rates that appeared to offer any significant benefits or advantages to the PREPIN/POLFAC/IMPSUM/SUMALL programs currently used for most Texas nonattainment areas. The researchers liked many features of the EMFAC/BURDEN/DTIM software; however, the emission rates contained in this software cannot be used in Texas.

CHAPTER IV

FINDINGS AND RECOMMENDATIONS

The MOBILE and EMFAC emission factor models discussed in Chapter II are reasonably good analysis tools for use with emissions models to develop estimates of mobile source emissions on a regional basis. The EMFAC model, because of its ability to disaggregate emissions into trip start, trip end, hot running, and diurnal emission factors, provides additional capability for analysis of specific transportation projects, transportation control measures, and transportation policy analysis that the MOBILE model does not enjoy. The MOBILE model was not developed with the intention of using it for these types of applications, but necessity and lack of any other approved emission factor model has resulted in it being used for these purposes.

There are concerns about the accuracy of both emission factor models. Current research is addressing some of the accuracy issues and both models are expected to continue to be improved with time.

All of the MOBILE-based emissions models, with the exception of IMPACT, apply trip start, trip end, and diurnal emissions on a VMT basis. As of July 1994, as far as the authors have been able to determine, EPA has not approved any emissions models based on MOBILE emission rates that break out trip start emissions in units of emissions per trip start separately from hot running emissions in units of emissions per mile. This is a current limitation of MOBILE and not of the emissions models. The travel models can provide estimates of the number of trip starts and the number of trip ends by traffic analysis zone for the study area. When trip end emission rates become available, the emissions models can be modified with little difficulty to use trip end emission rates.

The fact that trip end emission rates are not available separate from VMT related emission rates leads to difficulty in interpreting mobile source emission estimates. Research suggests that trip end and diurnal emissions, which are not VMT related, may have comprised as much as 69 percent of the total mobile source emissions in 1990.

This percentage of non-VMT related emissions may increase to 88 percent by the year 2010 (26). Research by EPA suggests that for light duty vehicles operating under stoichiometric conditions (an optimum fuel/air mixture), HC emissions are invariant with speed (i.e., HC emissions per mile do not vary with speed) when measured on a grams per second basis (27).

Because the MOBILE model is sensitive to changes in average speed and to VMT, the emissions models are sensitive to changes in average speed and VMT. As a result, transportation project selection, transportation control measure evaluation, transportation policy alternatives evaluation, and transportation conformity analysis are based on emission rates that tend to overstate the emission impacts associated with small changes in the average operational speeds at the link level and overstate the emission impacts of changes in VMT that occur at steady state velocities. Because of these limitations in the emission factor models and the emissions models, emphasis that probably would be more properly placed on reduction of trips is being placed on reduction in VMT.

It is important that users of the output of emissions models based on MOBILE model rates understand the interpretation of changes in emissions associated with small changes in average speed. For example, if a traffic improvement increases the operational speed of a link and, therefore, shows an improvement in HC emissions, the correct interpretation is that these are the emission changes that would be expected to occur between two driving cycles which differed by the changes in the two operational speeds, not to changes in two steady state speeds of the same magnitude.

The study recommends that the Texas Department of Transportation continue to use and enhance the PREPIN/POLFAC/IMPSUM/SUMALL programs for all regulatory applications of mobile source emissions. The emissions models evaluated in this study do not offer any significant advantages in features, accuracy, or ease of use over the PREPIN software. The researchers believe that all of the MOBILE based emissions models' reliance on changes primarily in operational speeds and VMT is overly simplistic and that additional research is appropriate to develop emission rates and emission programs that are sensitive to a wider variety of vehicle- related factors,

including trip start and trip end emissions, the number of vehicles and diurnal emissions, and vehicle operating modes (accelerations, decelerations, idle, and cruise).

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