REVIEW OF HIGHWAY POLLUTION MODELLING SOFTWARE

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Abstract: The estimation of highway pollution is always a difficult task because the vehicle emissions depend on several factors like traffic volume, speed, mode of start, fuel type and composition etc. Because of the complexity in estimating traffic emissions, some computer models were developed. Presently emissions factor models such as MOBILE, EMFAC, COPERT and dispersion models such as CALINE 4, Urban Air shed Model are available. Models are also necessary for forecasting and planning purposes. In this paper an attempt has been made to discuss the features of these computer models, through their input requirements and output.

1.0 INTRODUCTION

Highway emissions are directly related to traffic volume, vehicle type, speed and mode. It is intuitively clear that the more vehicles that occupy a particular space, the greater the emissions, not as apparent as the effect of vehicle type, and mode. For example, one would usually expect a heavy truck to emit more air pollution (e.g., CO) than an automobile. But a heavy truck, using diesel as fuel may emit less CO than a gasoline powered automobile under the same conditions. The speed also affects emissions in two ways. First, higher speeds demand for higher power, which leads to more fuel consumption and greater emissions. But with increased speed the vehicle departs an area more quickly so the emissions, usually reported in grams per mile, are reduced. Finally the vehicle mode can drastically affect the emissions. Because of the complexity in estimating the traffic emissions, modelling is required.

There exist two types of modelling processes, emissions quantification and dispersion modelling. The emission quantification modelling involves the estimation of amount of pollutant load in tonnes. For this purpose, the **motor vehicle emission factor models are required.** The emission factor models give the emission factor of a particular pollutant in grams per mile. The emission factors so obtained are then multiplied by the vehicle activity to get the total emissions. The dispersion modelling is used to predict the concentration of pollutant. These are useful to predict the ambient air quality.

Models are also necessary for forecasting and planning purposes. Models are presently being developed to combine meteorological forecast models with air pollution dispersion models to enable air quality forecasts.

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2.0 BASIC EMISSION ESTIMATION METHODOLOGY

The basic equation used for estimating motor vehicle emissions involves multiplying activity data by an appropriate emission factor. It is as given below.

$$\mathbf{Ep = VMT \times EFp} \quad (1)$$

Where:

Ep = Total emissions of pollutant p;
VMT = Vehicle Miles Travelled; and
EFp = Emission factor of pollutant p.

2.1 Motor Vehicle Emission Factor Models

The *emission factor* is defined as the estimated average emission rate for a given pollutant for a given class of vehicles. Instead of simple published emission factors, however, motor vehicle emission factors are derived from emission factor models. The reason for this is that emissions from motor vehicles are more complex and dynamic than most other source types. For example, changes in fuel characteristics, vehicle operating speeds, emission control technology, ambient temperature, and altitude can all affect emission factors. In order to account for these and other impacts, an emission factor model is normally used that includes the effects of many parameters. Estimates of vehicle emissions are obtained by multiplying an estimate of the distance traveled by a given class of vehicles by an appropriate emission factor.

The most advanced models are the U.S. EPA's MOBILE series (the current version is MOBILE 6), PART 5 and the EMFAC model developed by CARB. These models use statistical relationships based on thousands of emission tests performed on both new and used vehicles. In addition to standard testing conditions, many of these vehicles have been tested at other temperatures, with different grades of fuel, and under different driving cycles. Relationships have been developed for vehicles at varying emission control levels, ranging from no control to projections of in-use performance of future low-emission vehicle fleets.

Another emission factor model, the COPERT model (Andrias and others 1992) applies a methodology developed by the **CORINAIR** working group on emission factors to calculate emissions from road traffic in the EU countries.

2.1.1 MOBILE 6 Model (http://*www.epa.gov/otaq/models.htm)*

MOBILE is an EPA model for estimating pollution from highway vehicles. The MOBILE model can be used in every state of USA except California where the EPA permits the use of EMFAC. The MOBILE model consists of an integrated set of FORTRAN routines that generate hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NOx) emission factors for gasoline and diesel-powered on-road motor vehicles. Hydrocarbon emission factors can be expressed either as total hydrocarbons (THC), non-methane hydrocarbons (NMHC), volatile organic compounds (VOC), total organic gases (TOG), or non-methane organic gases (NMOG).

The first generation of the MOBILE model was created in the mid-1970s. The MOBILE model has subsequently undergone several updates and revisions in order to account for changing environmental legislation and technological advances. These updated versions also incorporate large amounts of newly collected emissions data in an attempt to more accurately estimate motor vehicle emissions. The most recent version of the MOBILE model is MOBILE 6.

MOBILE6 calculates emission factors for 28 individual vehicle types in low-and high-altitude regions of the United States. MOBILE6 emission factor estimates depend on various conditions, such as ambient temperatures, travel speeds, operating modes, fuel volatility, and mileage accrual rates.

MOBILE is used to calculate current and future emission inventories of these emissions at the national and local level. These inventories are used to make decisions about air pollution policy at the local, state and national level. Inventories based on MOBILE are also used to meet the federal Clean Air Act's State Implementation Plan (SIP) and transportation conformity requirements, and are sometimes used to meet requirements of the National Environmental Protection Act (NEPA).

The travel activity for MOBILE model is Vehicle Miles of Travel (VMT). The emission factors are multiplied by the VMT to obtain the emission estimates.

A list of MOBILE6 input parameters is provided below. Most of these inputs are optional because the model will supply default values unless alternate data is provided. Users must provide input data for calendar year, minimum and maximum daily temperature, and fuel volatility.

MOBILE 6 Input Parameters

- Calendar year
- Month (January, July)
- Hourly Temperature
- Altitude (high, low)
- Weekend/weekday
- Fuel characteristics (Reid vapor pressure, sulfur content, oxygenate content)
- Humidity and solar load
- Registration (age) distribution by vehicle class
- Annual mileage accumulation by vehicle class
- Diesel sales fractions by vehicle class and model year
- Average speed distribution by hour and roadway
- Distribution of vehicle miles travelled by roadway type
- Engine starts per day by vehicle class and distribution by hour
- Engine start soak time distribution by hour
- Trip end distribution by hour
- Average trip length distribution
- Hot soak duration
- Distribution of vehicle miles travelled by vehicle class

- Full, partial, and multiple diurnal distribution by hour
- Inspection and maintenance (I/M) program description
- Anti-tampering inspection program description
- Stage II refuelling emissions inspection program description
- Natural gas vehicle fractions
- HC species output
- Particle size cut off
- Emission factors for PM and HAPs

2.1.2 EMFAC (EMission FACtor) Model *(http://www.arb.ca.gov/msei)*

The California Air Resource Board (CARB) has released EMFAC 2002 as the latest version of the California Mobile Source Emission Inventory (Emission Factors) model for use in the state of California. The model development was coordinated with the California Department of Transportation (Caltrans). EMFAC 2002 has a Windows-based interface that allows a user to perform various types of analyses without invoking a command-line program.

The main function of the EMFAC Model is to generate emission factor information for the numerous vehicle classes, such as heavy-duty trucks and passenger cars. The EMFAC Model can provide emission estimates for the State as a whole and individually for each county, air district, or air basin. The EMFAC Model also provides emissions for each type of vehicle (cars, trucks, motorcycles, motor homes, etc.). In addition, the EMFAC Model can provide emission rates for various conditions (different temperatures, humidities, and speeds) to allow for the evaluation of special scenarios such as day-specific emissions inventories or assessment of control measure effectiveness. It can produce emission factors for Total Organic Gases, Carbon Monoxide (CO), Oxides of Nitrogen and Particulate matter.

The EMFAC Model is used for a variety of purposes. First, output from the EMFAC Model is used to create California's annual statewide emissions inventory. Because on-road motor vehicle emissions are a significant part of California's total emissions, the output from the EMFAC model provides an important part of the inventory.

The EMFAC Model is also used to evaluate the effectiveness of various motor vehicle control programs, as well as to show how California motor vehicle emissions have changed over time and are projected to change in the future.

The travel activity inputs for EMFAC model are Vehicle Hours of Travel (VHT), Number of trips and parking duration. The emission factors produced by the EMFAC model are used in the CALINE 4 dispersion model.

Input Requirements

- Geographical area (state, air basin, district, county)
- Speed fractions by scenario year, hour and vehicle class
- Calendar year, Month
- Model year for which the emission factors are needed

- Temperature, Relative Humidity and speed
- Vehicle trips per day (total trips per day, by vehicle class, by vehicle and fuel, by vehicle/fuel/hour)
- Total VMT (total trips per day, by vehicle class, by vehicle and fuel, by vehicle/fuel/hour)
- Inspection and maintenance (I/M) program description
- RVP for the calendar year and season
- Hourly temperature profile for the season
- Hourly RH profile for the season
- Speed fractions for the calendar year
- Idle times for heavy-duty vehicles

2.1.3 PART5 Emission Factor Model *(Mexico Emissions Inventory Program Manuals, May 1996)*

The U.S. EPA PART5 emission factor model utilizes FORTRAN routines that are similar to MOBILE to estimate particulate matter (PM) and sulfur oxide (SOx) emission factors for motor vehicles. Although the PART5 model resembles the MOBILE model in several respects, it is at an earlier stage of development because less particulate emission data have been collected. This is mainly the result of ozone precursors (TOG, CO, and NOx) being given higher priority than PM in the U.S. Consequently, some parameters that affect motor vehicle particulate emissions (e.g., temperature, inspection and maintenance [I/M] programs, fuel impacts) have not been modeled in PART5. Also, several assumptions in the model (i.e., driving cycles, fuel specifications, emission control systems, engine system deterioration rates) are valid only for the U.S. At the present time, the PART5 model has not been modified for outside use of the U.S.

2.1.4 COPERT Model (*Rentz et al., December 1999*)

The **CO**mputer **P**rogramme to Calculate **E**missions from **R**oad **T**ransport (COPERT) model (Andrias and others 1992) applies a methodology developed by the **CORINAIR** working group on emission factors to calculate emissions from road traffic in the EU (Eggleston and others 1991). COPERT can be used to estimate vehicle emission factors for carbon monoxide, non-methane hydrocarbons, methane, oxides of nitrogen, total particulate matter, ammonia, and nitrous oxide. Fuel consumption estimates are also provided. Emission factors are estimated for urban, rural, and highway driving with an average automobile speed of 25 kilometers per hour, 75 kilometers per hour, and 100 kilometers per hour, respectively. COPERT accounts for cold-start emissions and evaporation losses, and uses an average trip length of 12 kilometers. The latest version in this series is COPERT III.

Input requirements for COPERT III

- Fuel specifications
- Monthly temperatures
- Fuel reid vapour pressure
- Cold start parameters for average trip length
- Monthly canister efficiency
- Fleet Information
- Circulation Information

Using this information the model calculates the emission factors for CO, NO_x, VOC, and PM for hot-stabilized and cold excess starts and evaporative emissions.

3.0 DISPERSION MODELLING

A Dispersion Model is a tool used to predict the concentration of a contaminant at a receptor resulting from point, area or volume exhaust sources. Dispersion models use mathematical algorithms that simplify atmospheric dispersion and dilution phenomena. Typical model input variables include: contaminant emission rates; stack height; gas temperature; discharge velocity; flow rate; terrain topography; property dimensions; and building elevations. Dispersion models are used to predict the impact of contaminant emissions at locations surrounding the source.

For vehicular emissions dispersion modelling the following models are used:

- HIWAY
- CAL3QHC
- CALINE 4
- UAM

The detailed description of the models is given below.

3.1 HIWAY: A Highway Air Pollution Model

The HIWAY (*http://cesimo.ing.ula.ve/GAIA/models/hiway.htm)* model was developed by U.S. EPA for the evaluation of air pollution due to a motorway in flat terrain and for a given traffic condition (assumed to be equivalent to a linear pollution source). It is based on the Gaussian plume approximation, which is adapted to represent the pollution due to each lane, and corrected to account for low wind conditions.

HIWAY cannot deal with severe obstacles to the air flux (buildings, large tree areas) or with complex terrains.

3.2 Carbon Monoxide Dispersion Modelling

CO emissions are usually generated during peak-hours and are measured in grams per vehicle-mile for use in dispersion models. These models use meteorological, transportation, emission, and other site-specific information to predict concentrations of pollutants downwind from the modelled source.

To model the dispersion of CO, models of the Gaussian line-source types are most widely used. If one considers a single isolated point source, such as the smoke stack of a power plant, the plume rises because it is warmer than the surrounding air. As the plume is adverted downwind, it is subjected to atmospheric turbulence that causes it to diffuse from the source; therefore, pollutant concentrations decrease with increasing distance from the centreline of the plume.

The spreading and wafting of plumes will be influenced by wind speed, direction, and various other dispersion parameters. As the wind speed increases, the distance between the particles within the plume will increase. The net effect is that pollutant concentrations are generally inversely proportional to the wind sped.

The stability and mixing height will also influence the dispersion of the plume. If there is a high degree of atmospheric turbulence, this will tend to spread the plume more rapidly. If the plume has spread vertically so that upper margin of the plume is contained by an inversion, the mixing height is reduced. This increases the concentration of the pollutant between the ground and the base of the inversion layer.

The height of the emission source also affects the ground level concentrations. The greater the height of the emission, the further the plume will have to spread, before significant concentrations are observed at the ground level.

These factors are the principles behind the Gaussian plume models, such as CAL3QHC and CALINE-4, used in mobile source-related analyses. These models calculate how pollutants are dispersed by representing the relationships discussed in the form of mathematical equations.

CAL3QHC is the EPA-required dispersion model to be used in all areas of USA, except California, which has developed the CALINE-4 model.

3.2.1 CALINE 4 Model *(Paul Benson, P.E. June 1989)*

CALINE 4 is a fourth generation line source air quality model developed by the California Department of Transportation that predicts CO impacts near roadways. Its main objective is to assist planners to protect public health from adverse effects of excessive CO exposure. The model is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over roadways. For given source strength, meteorology, and site geometry and site characteristics the model can reliably predict (1-hour and 8-hours) pollutant concentrations for receptors located within 150 meters of the roadway. The model can also predict the worst-case scenario (combination of wind speed, direction and stability class), which produces the maximum pollutant concentrations at the pre-identified receptor points along the highway. CALINE4 comes with a Windows user interface.

Input requirement for CALINE 4

CALINE 4 highway dispersion model requires the following data as input:

- Traffic parameters: Traffic volume (hourly and peak), traffic composition (two wheelers, three wheelers, cars, buses, goods vehicle etc.), type of the fuel used by each category of vehicles, fuel quality, average speed of the vehicles.
- Meteorological parameters: Wind speed, Wind direction, stability class, mixing height
- Emission parameters: Expressed in grams /distance travelled. It is different for different categories of vehicles and is a function of type of the vehicle, fuel used, average speed of the vehicle and engine condition etc.

- Road geometry: Road width, median width, length and orientation of the road, number and length of each links.
- Type of the terrain: Urban or rural, flat or hilly
- Background concentration of pollutants
- Receptor location

3.2.2 CAL3QHC Model *(http://www.seas.upenn.edu/~sys562/ug/cal3qhc.html)*

CAL3QHC is generally used for modelling emission at intersections, although it can be used to model free-flow conditions as well.

Input requirements for CAL3QHC

To run CAL3QHC, the following inputs are required hourly:

- Wind speed in meters per second,
- Wind angle with respect to the positive Y-axis in degrees,
- Atmospheric-stability measure,
- Mixing height and width in meters,
- Receptor information (e.g., number, height, angle of observation, and distance from the road),
- Roadway characteristics (e.g., number of lanes and segment length),
- Section type (e.g., at grade, fill, bridge, and depressed),
- Coordinates of the end points of the link,
- Signal cycle in use,
- Free-flow and idle emission factors (obtained from the MOBILE models),
- Background concentrations of the specific pollutant, and
- Height of the pollutant source.

CAL3QHC works by considering the intersection as a series of links on which vehicles are in different modes of operation. The model takes the input data and calculates average queue lengths over the specified time. Different emission factors from the MOBILE5a model are then applied, on the basis of whether the vehicle is in idling (queued) or in free flow. Output is the concentration of the pollutant in parts per million. CO estimates are produced for both 1- and 8-hr periods during the peak CO season, generally the winter.

3.3 Ozone Dispersion Modelling

3.3.1 The Urban Airshed Model – UAM *(http://www.epa.gov/asmdnerl/urban.html)*

Ozone formation is predicted using photochemical dispersion models that use mobile source emissions as inputs. The most widely used regional dispersion model is the UAM. UAM is an urban scale, three-dimensional, grid type numerical simulation model. This model incorporates a three-dimensional (3-D) photochemical grid to simulate the atmosphere. Its purpose is to calculate concentrations of pollutants by simulating physical and chemical processes in the atmosphere that affect pollutant concentrations. The UAM uses atmospheric diffusion or species continuity equations that represent a mass balance in which all of the relevant emissions, transport, diffusion, chemical reactions, and removal processes are expressed mathematically.

Input requirement for UAM

For urban applications the model is usually used to simulate a 2- or 3-day ozone episode. The data requirement for this is as follows:

- Hourly estimates of the height of the mixed layer, which requires day-specific upper-air temperatures and wind data at various times;
- A 3-D wind-field for each hour;
- Ambient temperature, humidity, atmospheric pressure, solar radiation, cloud cover, and the chemical species to be simulated; and
- Hourly gridded emissions for NO_x and VOCs. (VOCs must be classified by carbon-based class because the UAM employs carbon-based chemical kinetic mechanisms.)

Output from UAM

Some typical output of the UAM include the following:

- Average concentrations by hour and grid square for all species and
- Instantaneous concentrations for each species by grid square at the beginning of the average period

4.0 SCOPE OF THE MODELS AND CONCLUSIONS

All the models described above are designed for U.S. fleet only except the COPERT Model. The Models include the defaults, which are designed to represent the "national average" input data values. Users who desire a more precise estimate of local emissions can substitute information that more specifically reflects local conditions. Use of local input data will be particularly common when the local emission inventory is to be constructed from separate estimates of roadways, geographic areas, or times of day, in which fleet or traffic conditions vary considerably.

For instance, the Environment Canada has developed a Canadian version of the MOBILE5, named as MOBILE 5.C *(Anderson, Kanaroglou et al, TRR 1520)* to adjust the differences between the Unite States and Canada. Similarly, In order to account for possibly different vehicle fleets and driving behavior in Mexico, the MOBILE model has been modified for the Mexico City, Monterrey, and Ciudad Juárez metropolitan areas *(Mexico emissions Inventory Program Manuals)*. A technology equivalence matrix for exhaust and evaporative emission factors were developed. It can be seen that a 1994 Mexican light-duty gasoline vehicle (LDGV) would be equivalent to a 1988 U.S. LDGV. In some instances, a certain Mexican model year might be equivalent to one U.S. model year for exhaust control technology and another for evaporative control technology.

Before applying these models to the Indian traffic conditions, there is need for adjustment of the model to reflect the Indian conditions. Otherwise, the results will produce uncertain results.

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