DEVELOPMENT AND APPLICATION OF A MICRO SCALE EMISSION FACTOR MODEL (MicroFac) FOR MOBILE SOURCE EMISSIONS

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ABSTRACT

A new micro scale emission factor model (*MicroFac*) for predicting gaseous and particulate matter motor vehicle emissions and fuel consumption has been developed. *MicroFac* uses a disaggregated algorithm, based on the real on-road vehicle fleet, to calculate real-time site-specific emission rates. The model requires vehicle fleet characterization, speed and ambient temperature. The performance of *MicroFac* was evaluated for CO, NOx, CO_2, PM_{10}, and $PM_{2.5}$ in roadway tunnels for cases where detailed traffic fleet characteristics were known. In general, the model has shown very encouraging performance. The MicroFac algorithm is suitable for application at a range of temporal (minutes to hours) and spatial (metres to kilometres) scales where vehicle count data are available. MicroFac is primarily designed to be used with dispersion models and to support remote sensing studies in converting emission concentrations to g/km units.

INTRODUCTION

Existing U.S. models include the *MOBILE* emission model (used in the U.S., except California), and *EMFAC* (used in California). These are based on Vehicle Miles Travelled (VMT) and are aggregated temporally and spatially. A number of independent evaluation field studies on *MOBILE* models have demonstrated the unreliability of its results.[1,2,3,4,5] The U.S. Environmental Protection Agency (EPA) is now developing a modeling system known as **MO**tor **V**ehicle **E**mission **S**imulator (*MOVES*)[6] to replace *MOBILE*. Currently, *MOVES* estimates fuel consumption for all on-road sources over the entire U.S. at the county level. A GIS-based model of automobile exhaust emissions known as the Mobile Emission Assessment System for Urban and Regional Evaluation (*MEASURE*) has been developed to estimate hourly transportation and gridded automobile exhaust emission estimates based on a geographical area's vehicle registration data, accurate digital road data set, travel demand forecasting model output, and zone-based socioeconomic data.[7] A Comprehensive Modal Emissions Model (*CMEM*)[8] was developed at the University of California-Riverside in collaboration with the University of Michigan and Lawrence Berkeley National Laboratory. *CMEM* is capable of predicting second-by-second vehicles exhaust emissions and fuel consumption for light-duty vehicles. Motor vehicle emissions can also be estimated from traffic information obtained from the Transportation Analysis and Simulation System (*TRANSIMS*), which is a part of the Travel Model Improvement Program being developed by Los Alamos National Laboratory.[9]

Motor vehicle emission models are difficult to evaluate on their own; dispersion has either to be avoided by confining the emissions in a tunnel or included by applying dispersion models with their associated uncertainties.[10] Hence, tunnels provide the best environment for the mobile source emission model evaluation. Except *MOBILE* and *EMFAC* models, no emission model validation study is available to demonstrate the application of model in real-world.

This paper discusses a micro scale emission factor model (*MicroFac*) and its application in air quality modeling and emission inventories. We have completed *MicroFac* models to calculate emissions of CO, NOx, PM_{10}, and $PM_{2.5}$. We have also developed a fuel consumption model that can be used to calculate CO_2 emission factors assuming that the carbon content of the fuel is fully oxidised into CO_2.

MicroFac MODEL

Accuracy of an emission model depends upon the quality and quantity of data used to construct the model. Therefore, *MicroFac* model utilizes the existing up-to-date data without requiring for new measurements. The main sources of data used for *MicroFac* model was obtained from peer-reviewed literature including data from EPA[11], European Environment Agency data[12] and Coordinating Research Council.[13] MicroFac models are suitable for modeling emission and fuel consumption between 1990 and 2020, and can calculate emission factors for on-road vehicles on an unlimited number of roads. The maximum number of lanes is normally eight, although a road of more than eight lanes can be treated as a parallel road network. The *MicroFac* modelling structure is summarized in the figure 1.

MicroFac Algorithm

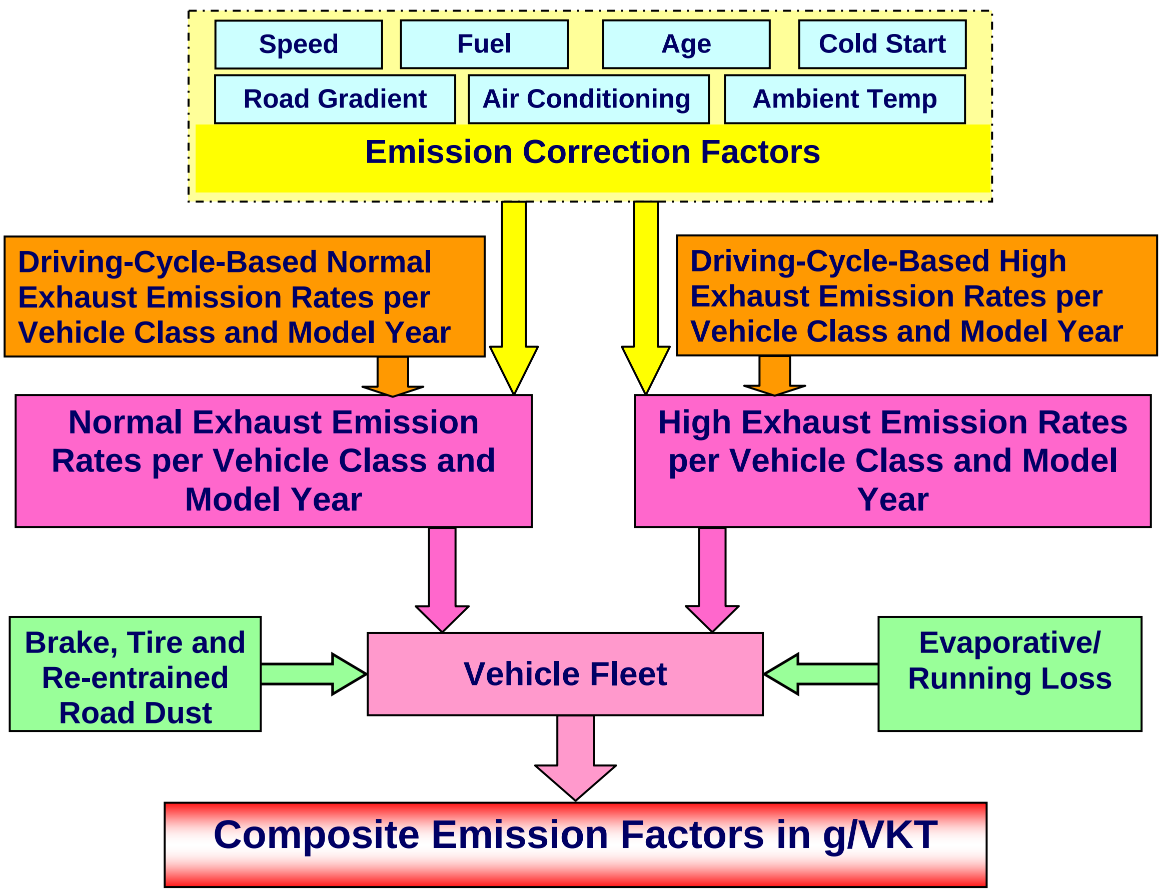
The algorithm used to calculate emission factors in *MicroFac* is disaggregated based on the on-road vehicle fleet, and calculates emission rates from a real-time site-specific fleet. *MicroFac* starts with geographically resolved data, for example modeling traffic fleet on an individual length of road. Emissions factors are calculated for site-specific on-road traffic fleet, e.g. CO emissions in g/VKT. Total emissions for a geographical area of interest can then be obtained by summing contributions from individual road segments. This approach gives a shorter averaging time, such as a single road during a specific hour more accurately. *MicroFac* performance with the available tunnel data[5,14] have shown very encouraging results for U.S. and Canadian vehicle fleet.[15,16,17]

MicroFac requires only a few input variables to characterize the fleet. The main variables give the time and day of the year, vehicle speed, the ambient temperature and relative humidity, and specify the percentage of vehicles exceeding certain emission standards (high emitting vehicles). Primary emission rates are calculated for both light and heavy – duty vehicle classes based on their fuel use, weight and emission categories (normal and high emitters). High emitters are defined as those vehicles which are poorly maintained and will result in excess emissions compared to normal emitting vehicles. The fraction of high emitting vehicles present in the fleet can be determined by on-road survey, remote sensing and/or Inspection and Maintenance (I/M) program. *MicroFac* will calculate the fraction of vehicles in each category for a 25-year age-wise distribution and then groups these into normal and high emitting categories. Then the vehicle miles accumulated for each vehicle will be calculated based on the model year. The vehicle miles accumulated are then used to calculate normal and high emission rates in g/VKT. *MicroFac* then calculates correction factors for vehicle type, model year and emission level. Finally, the individual emission rates for the specified vehicles are calculated, and these are multiplied by the fraction of vehicles in that model year and vehicle class. The sum of these yields the composite emission factor (CEF) for the specified vehicle fleet.

$$\mathbf{CEF} = \sum_{i,j} \mathbf{ER}_{i,j} \times \mathbf{VEH}_{i,j}$$

Where $ER_{i,j}$ is the Composite emission rate for vehicle type i and model year j, and $VEH_{i,j}$ is the fraction of vehicles for vehicle type i and model year j.

Figure 1. MicroFac modelling structure



MicroFac Input Requirements

MicroFac requires a few input variables, which are necessary to characterize the site-specific real-time fleet. If local fuel properties, length of trip and vehicle fleet data is unavailable, default values can be used. *MicroFac* includes the default values between 1990 and 2020 for Ontario, Canada. The following input are requires running the model.

- Date and time
- Average fleet speed
- Ambient temperature and relative humidity
- Road gradient
- Gasoline fuel properties, such as density, sulphur, volatility, aromatics, oxygen, olefins, fuel distillation (E100 - % of fuel evaporated at 100ºC, E150 - % of fuel evaporated at 100ºC) and heavy metals
- Diesel fuel properties, such as density, sulphur, RVP, cetane number, PAH, volatility (T95 - temperature at which 95% of a particular diesel fuel distils in a standardized distillation test) and heavy metals
- Length of trip (to calculate fraction of distance travel with cold running emissions)
- Vehicle fleet composition, age distribution and high emitters in the fleet.

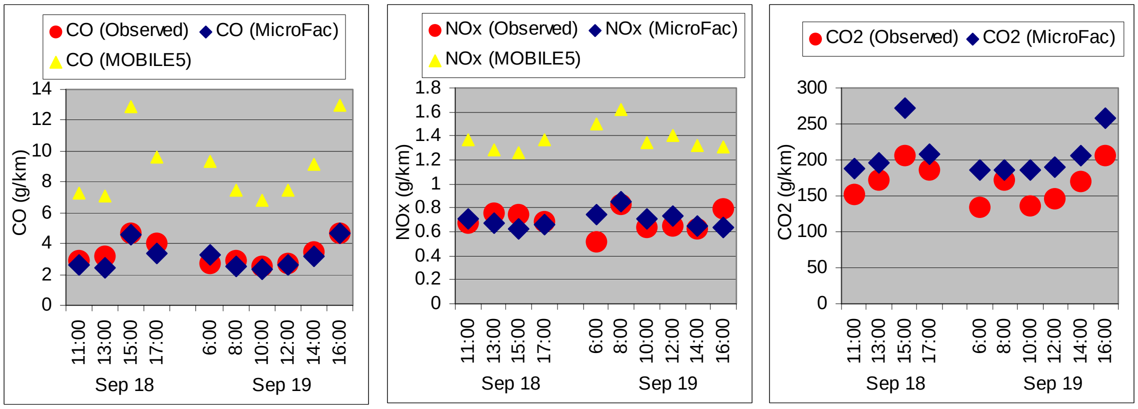
MICROFAC EVALUATION

Roadway tunnel studies are considered very effective in determining fleet emission rates from in-use vehicles.[18] Therefore, *MicroFac* was evaluated using reported tunnel study data from Massachusetts, New York and Arizona in 1995[5]; and Pennsylvania in 1999.[14] The input data, including vehicle fleet distribution and model years, required to run *MicroFac* was known for these studies. The comparison of modeled and observed emission factors along with the brief discussion of tunnels considered for this study is discussed below.

Callahan Tunnel, Boston, Massachusetts.

The Callahan Tunnel is an underwater vehicular tunnel under Boston Harbour in Boston, Massachusetts. It is a two-bore tunnel, with two lanes in each bore, carrying traffic between North Boston, East Boston and Logan International airport. This tunnel has a length of 1.5 km with no curvature. The road grade varies from -3.8 percent to +3.25 percent. Surveys (ten runs) were conducted from September 18 (11:00 AM) to September 19 (5:00 PM), 1995. Generally, the traffic flow was smooth and the traffic fleet was dominated by light-duty vehicles (< 8500 lbs), which comprised from 93.5 to 97.7 percent of all vehicles. The average speed and ambient temperature respectively ranged from 22.6 to 49.1 km/h and 10.0 to 20.6° C. Figure 2 presents the observed and MicroFac modeled emission factors for CO, NOx and CO_2. MOBILE5 modeled emission factors were available for CO and NOx. The average observed and *MicroFac* values for CO are 3.4 and 3.2 g/km, respectively; for NOx are 0.7 and 0.7 g/km, respectively; and for CO_2 are 168.2 and 207.5 g/km, respectively.

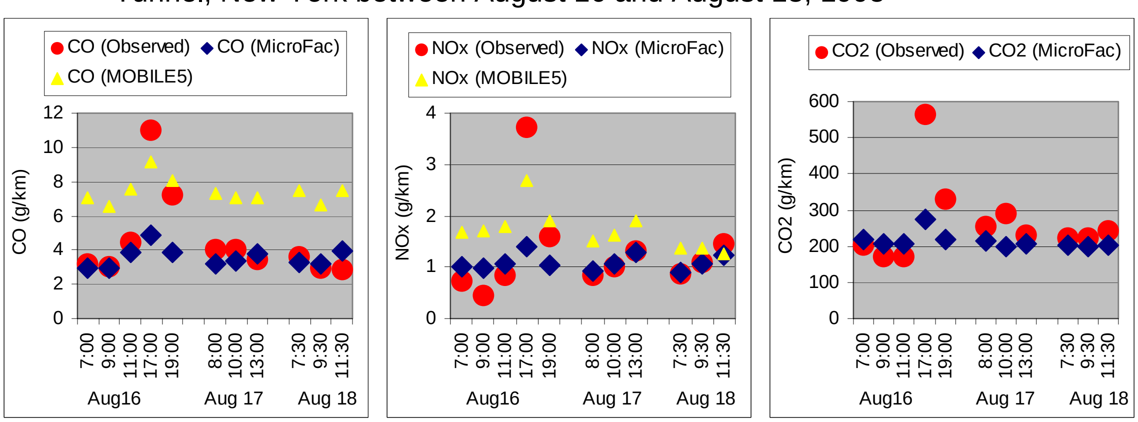
Figure 2. Observed and MicroFac modeled emission factors for CO, NOx and CO_2 in Callahan Tunnel, Boston between September 18 and September 19, 1995.



Lincoln Tunnel, New York

The Lincoln Tunnel is an underwater tunnel under the Hudson River between Weehawken, New Jersey and Manhattan Island. It is a three-bore tunnel with two lanes in each bore. Experiments were conducted in the South tube of the tunnel, carrying eastbound traffic from New Jersey to New York. This tunnel has a length of 2.4 km with no curvature and grade varying from -3.8 percent to +3.25 percent. Studies (eleven runs) were conducted between August 16 (7:00 AM) and August 18 (12:30 PM), 1995. Light-duty vehicles (< 8500 lbs) comprised only 82.6 to 90.7 percent of the vehicle fleet in comparison to the Callahan Tunnel. The average speeds were lower (32.6 to 48.0 km/h) and the ambient temperatures were higher (28.1 to 32.6° C). Note the percentage of heavy-duty vehicles is high in this case in comparison to the previous (Callahan) case, which shows that the precise split of heavy-duty vehicles is also important. Figure 3 presents the observed and MicroFac modeled emission factors for CO, NOx and CO_2. MOBILE5 modeled emission factors were available for CO and NOx. Two runs on August 16 (17:00 and 19:00) have shown very high values, probably may be presence of a few very high emitting vehicles. The average observed and *MicroFac* values excluding runs 4 and 5 for CO are 3.5 and 3.4 g/km, respectively; for NOx are 0.9 and 1.1 g/km, respectively; and for CO_2 are 269.4 and 213.7 g/km, respectively.

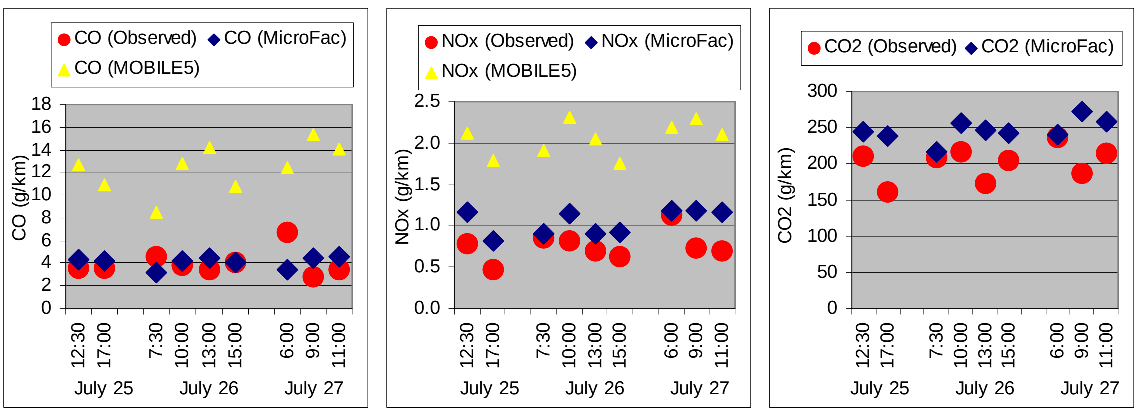
Figure 3. Observed and MicroFac modeled emission factors for CO, NOx and CO2 in Lincoln Tunnel, New York between August 16 and August 18, 1995



Deck Park Tunnel, Phoenix, Arizona

The Deck Park Tunnel is along an urban freeway (Interstate-10), running east-west under Deck Park in downtown Phoenix. It has three bores, including an unused center bore, and has five lanes and two emergency lanes in the south and north bores. This tunnel has a length of 0.8 km with a slight curvature and grade. Nine runs were carried out between July 25 and 27, 1995. This tunnel represents the evaluation of the model at high speeds (94.1 to 99.0 km/h) and high ambient temperatures (29.4 to 46.1° C). Light-duty vehicles comprised between 92.7 to 97 percent of the overall vehicle fleet. Figure 4 shows the observed and MicroFac modeled emission factors for CO, NOx and CO_2. MOBILE5 modeled emission factors were available for CO and NOx. The average observed and *MicroFac* values for CO are 4.0 and 4.1 g/km, respectively; for NOx are 0.7 and 1.2 g/km, respectively; and for CO_2 are 201.3 and 246.3 g/km, respectively.

Figure 4. Observed and MicroFac modeled emission factors for CO, NOx and CO2 in Deck Park Tunnel, Phoenix between July 25 and July 27, 1995



Tuscarora Mountain Tunnel, Pennsylvania Turnpike, Pennsylvania

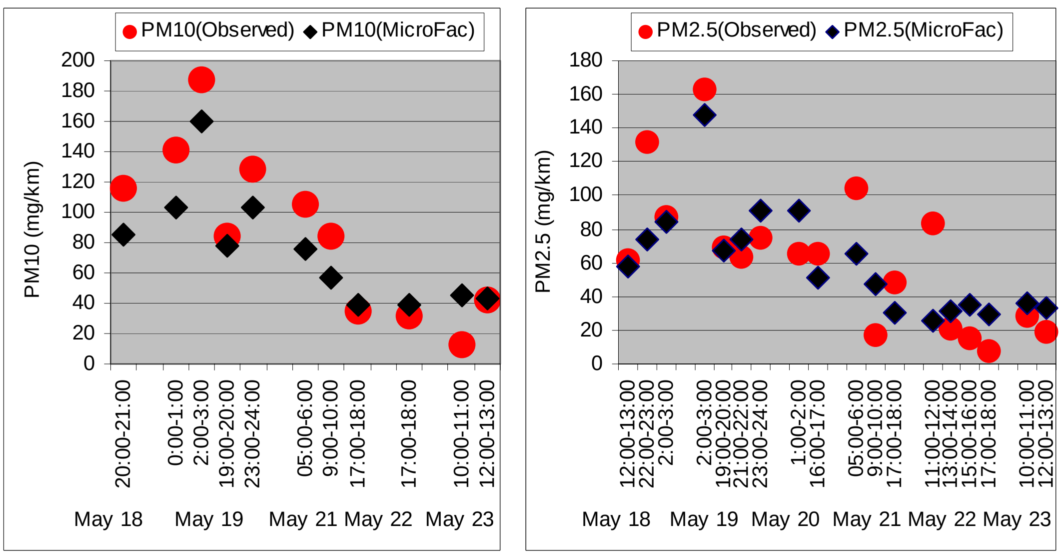
The Tuscarora Mountain Tunnel is along Interstate 76 (I-76), also called the Pennsylvania Turnpike running east-west through the Tuscarora Mountain in south central Pennsylvania. It is a two-bore tunnel, two lanes per bore and 1.6 km long. The tunnel is flat (grades +0.3% towards the middle from the either end) and straight. Studies were conducted between May 18 and 22, 1999. All experimental runs were one hour duration except the last which was two hour duration. The speeds varied from 85.6 to 99.3 km/h and light-duty vehicles (<8500 lbs) fraction from 13.7 to 88.6 percent. The precise traffic fleet distribution including model years of the vehicles was known for each run.[19]

PM_{10} measurements were performed using the DustTrak 8520 Aerosol Monitor (TSI, Inc., St. Paul, MN), which is a portable, battery operated, laser-photometer that uses light scatter technology to determine mass concentration in real-time. It is reported that traditional method of collecting sample on filters are prone to error in short-duration field studies because of the small size of samples[20,21] and these instruments perform better than traditional filter measurements.[22,23]

$PM_{2.5}$ mass measurements were performed using IMPROVE samplers.[24] The standard IMPROVE sampler has four modules, each consisting of a size selective inlet for PM_{10}, a cyclone to provide a $PM_{2.5}$ particle size cut-off based on the flow rate, collection substrates, a critical orifice that provides the proper flow rate for the desired particle size cut-off, and a vacuum that produces the flow. In this study, the PM_{10} module was not used.

Figure 5 compares the observed and MicroFac emission factors for $PM_{2.5}$ and PM_{10}, respectively. Note the modeled emission factors do not include the re-entrained road dust. The average observed and *MicroFac* values for $PM_{2.5}$ (18 runs) are 63 and 59 mg/km, respectively, and for PM_{10} (11 runs) are 88 and 75 mg/km, respectively.

Figure 5. Observed and MicroFac modeled emission factors for PM_{10} and $PM_{2.5}$ in Tuscarora Tunnel, Pennsylvania between May 18 and May 23, 1999



MicroFac APPLICATION

The main application of *MicroFac* models is providing input to dispersion models and emission estimates at low temporal and fine spatial scale. In addition, *MicroFac* models can also used in supporting emission estimates from remote sensing studies.

Air Quality Modeling

The pollutant concentrations estimated by air quality dispersion models are highly sensitive to the quality of vehicle emissions input.[25] Detailed and correct knowledge of emission characteristics is therefore an essential prerequisite for a useful model. *MicroFac* model is designed to calculate site-specific emission rates at any temporal resolution (e.g. hourly for *CALINE4* and *AERMOD*) applications. An integrated *MicroFac* and *CALINE4* or *AERMOD* modeling system can provide a very useful tool in predicting ambient concentration near roadways and in human exposure assessment. This integrated modeling system has been used successfully to calculate vehicle generated contributions to $PM_{2.5}$ emissions near the Ambassador Bridge in Windsor, Ontario.[26]

Data from Remote Sensing

Remote sensing devices (RSD) are used to measure roadside emissions from individual vehicles and to identify on-road normal and high emitting vehicles. The data collected from RSD is expressed in percent or ppm. In view of large amount of data and the uncertainty in assuming fuel consumption rate, it is necessary to calculate the fuel consumption rate depending on the vehicle speed and meteorological conditions. This will help in expressing vehicle emissions into units (g/km) useful for the Government and Science community and comparing with standard emissions over a driving cycle. *MicroFac* fuel consumption model can be used to convert these units into g/km units. The application of *MicroFac* fuel consumption model in calculating CO_2 emission factors has been demonstrated in **MicroFac Evaluation** section. In addition, fuel based emission inventories developed from the remote sensing studies[27,28] and fuel sales data can be disaggegrated spatially and temporally using vehicle count information and *MicroFac* models.

CONCLUDING REMARKS

A micro scale emission factor model for predicting site-specific real-time motor vehicle emissions has been developed, which captures virtually all the real-world information for the North American vehicle fleet. The evaluation of *MicroFac* has shown very good performance. The methodology for *MicroFac* uses the existing databases without requiring for new measurements. *MicroFac* has been developed for micro scale applications and utilising remote sensing emission concentrations data to convert into g/km units. *MicroFac* has been designed to estimate emission factors from on-road traffic and can be directly used to input dispersion models, such as *CALINE4* and *AERMOD*, and to support reliable modeling of human exposures. *MicroFac* is also appropriate for comparative analyses, for example comparing the potential impact of one traffic control measure versus another.

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