Application of a Microscale Emission Factor Model for Particulate Matter (MicroFacPM) to Calculate Vehicle Generated Contribution of $PM_{2.5}$ Emissions

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ABSTRACT

The United States Environmental Protection Agency's (EPA) National Exposure Research Laboratory is developing improved methods for modeling the source through the air pathway to human exposure in significant microenvironments of exposure. As a part of this project, we developed a microscale emission factor model for predicting real-world real-time motor vehicle particulate matter (PM_{10} and $PM_{2.5}$) (MicroFacPM) emissions, which uses available information on the vehicle fleet composition. This paper presents the use of MicroFacPM to calculate the contribution of $PM_{2.5}$ per vehicle class, age-wise, gasoline, diesel, brake wear and tire wear sources. The contribution of emission factors is presented for two scenarios: first the Tuscarora Mountain Tunnel, on the Pennsylvania Turnpike, PA and second for Capital Boulevard, in Raleigh, NC. In the Tuscarora Tunnel, average contributions of $PM_{2.5}$ emission factors were 2.4 percent from 58.7 percent LDGV&T, 2.9 percent from 0.4 percent LDDV&T, 0.04 percent from 0.8 percent HDGV, 3.6 percent from 1.5 percent HDDV45, 1.1 percent from 0.9 percent HDDV6, 14.7 percent from 6.5 percent HDDV7, 20.0 percent from 9.4 percent HDDV8A, 51.6 percent from 21.8 percent HDDV8B, and 3.7 percent from tire wear emissions. For the Capital Boulevard, Raleigh, NC, scenario the largest $PM_{2.5}$ contribution was from light-duty diesel trucks (37% emissions from 2% vehicles) followed by heavy-duty trucks class 8 (22% from 1% vehicles).

INTRODUCTION

In response to request from Congress, the National Research Council established a Committee to Review Environmental Protection Agency's Mobile Source Emission Factor (MOBILE)[1] Model in October 1998. The Committee's findings were published recently.[2] A few of the concerns raised by the Committee included the limitations of MOBILE models by stating "Originally, MOBILE was developed to estimate overall emissions levels, trends over time, and the effectiveness of mobile-source emissions control strategies." This report indicated "An emission factor model is fundamental for assessing the nature and magnitude of on-road motor vehicle emissions and their impacts on ambient air quality." The report followed the earlier published NRC recommendations, which identified outdoor measures versus actual human exposure, characterization of emission sources, air-quality-model development and testing as among the top 10 research areas of highest priority.[3]

The mobile source emission models, such as MOBILE (used in the United States except California) and EMFAC[4] (used in California only), are suitable for supporting regional scale modeling and emission inventories. These emission models have not been designed to estimate real-time emissions needed to support human exposure studies near roadways. Hitherto, in the absence of microscale emission models, these models are used for microenvironmental modeling applications. The site-specific real-time real-world modeling is necessary for assessing human exposures in different roadway microenvironments, such as in-vehicles and near roadways; and to understand complex relationships between roadway fixed-site ambient monitoring data and actual human exposure.

The mutagenic and carcinogenic effects of particulate matter, especially from diesel-fueled vehicles are is well known.[5,6,7,8,9] The United States Environmental Protection Agency's (EPA) National Exposure Research Laboratory has an ongoing project to improve the methodology for modeling human exposures to motor vehicle emissions. The overall project goal is to develop improved methods for modeling from the source through the air pathway to human exposure, within significant microenvironments of exposure. Roadway dispersion models use the source strength of particles or gases in terms of concentration per unit distance (e.g. milligrams per mile, mg/mi) as an input to predict particle or gas concentrations in space or time. Detailed and correct knowledge of the emission characteristics is therefore an essential prerequisite to developing a reliable human exposure model.

In view of the above need, a microscale emission factor model for predicting real-world real-time motor vehicle particulate matter (MicroFacPM) emissions for TSP (total suspended particulate matter), PM_{10} (particulate matter less than 10 μm aerodynamic diameter) and $PM_{2.5}$ (particulate matter less than 2.5 μm aerodynamic diameter) has been developed.[10,11] The sensitivity analysis and evaluation of MicroFacPM has shown very encouraging results.[12]

This paper presents an application of MicroFacPM to calculate the contribution of motor vehicle generated $PM_{2.5}$ emissions per vehicle class, year-wise and sources.

MicroFacPM MODEL

The algorithm used to calculate emission factors in MicroFacPM is disaggregated based on the on-road vehicle fleet, and calculates emission rates from a real-time site-specific fleet. The model requires only a few input variables that are necessary to characterize the real-time fleet. The main input variables required are the description or characterization of on-road vehicle fleet, time and day of the year, ambient temperature, relative humidity and percentage of smoking vehicles. The speed correction factor is calculated for speeds other than 19.6 mi/h for heavy-duty diesel vehicles. The fuel additive correction factor is accounted for if oxygenated fuel is used with gasoline vehicles. The cold engine correction factor is calculated for the vehicles running with cold engines based on their trip length and ambient temperature. The air conditioning correction factor for light-duty gasoline vehicles is applied for the ambient temperatures (heat index) greater than 65°F.

The primary emission rates were calculated per vehicle type and model year based on their emission categories (normal and non-normal). MicroFacPM first calculates the fraction of vehicles in each category for a 25-year age-wise distribution and then groups these into either the normal and non-normal emitting categories. Then the vehicle miles accumulated for each vehicle are calculated based on the model year. The vehicle miles accumulated are used to calculate primary normal emission rates in mg/mi for heavy-duty diesel vehicles (>8500 lbs) and buses. MicroFacPM then calculates various correction factors based on the vehicle type, model year and emission level. Finally, corrected emission rates for individual vehicles are calculated, and multiplied by the fraction of vehicles of each model year and vehicle class. The sum of these yields composite emission factor for the on-road vehicle fleet.

$$CEF = \sum_{i,j} (ER_{i,j} \times VEH_{i,j})$$

Where,
CEF = Composite emission factor,
$ER_{i,j}$ = Composite emission rate for vehicle type i and model year j, and
$VEH_{i,j}$ = Fraction of vehicles for vehicle type i and model year j.

The schematic diagram of MicroFacPM are shown in Figure 1. The vehicle classification and symbols used in MicroFacPM is listed in Table 1.

Figure 1. The schematic diagram of the MicroFacPM general model structure

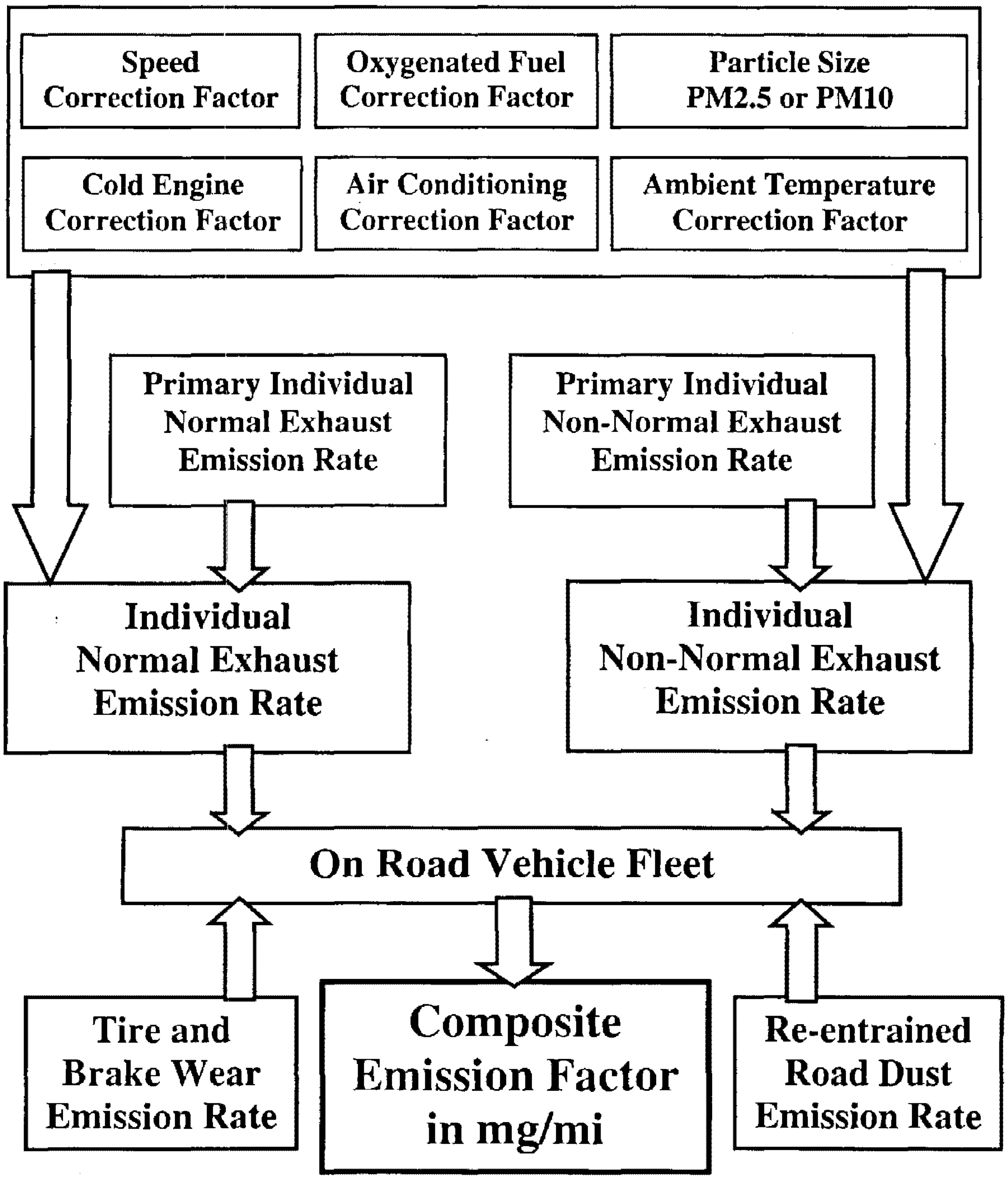


Table 1. Vehicle classifications used in MicroFacPM

SN	DESCRIPTION	Gross Vehicle Weight (lbs)	Symbol
Light-duty vehicles (LD)			
Gasoline vehicles			
1	Light-duty gasoline vehicles (cars)	0-6000	LDGV
2	Light-duty gasoline trucks 1	0-3750	LDGT1
3	Light-duty gasoline trucks 2	3750-6000	LDGT2
4	Light-duty gasoline trucks 3	6001-7250	LDGT3
5	Light-duty gasoline trucks 4	7251-8500	LDGT4
6	Motor cycles	All	MC
Diesel vehicles			
7	Light-duty diesel vehicles (cars)	0-6000	LDDV
8	Light-duty diesel trucks 1	0-3750	LDDT1
9	Light-duty diesel trucks 2	3750-6000	LDDT2
10	Light-duty diesel trucks 3	6001-7250	LDDT3
11	Light-duty diesel trucks 4	7251-8500	LDDT4
Heavy-duty vehicles (HD)			
Gasoline vehicles			
12	Heavy-duty gasoline vehicles class 2B	8501-10000	HDGV2B
13	Heavy-duty gasoline vehicles class 3	10001-14000	HDGV3
14	Heavy-duty gasoline vehicles class 4	14001-16000	HDGV4
15	Heavy-duty gasoline vehicles class 5	16001-19500	HDGV5
16	Heavy-duty gasoline vehicles class 6	19501-26000	HDGV6
17	Heavy-duty gasoline vehicles class 7	26001-33000	HDGV7
18	Heavy-duty gasoline vehicles class 8A	33001-60000	HDGV8A
19	Heavy-duty gasoline vehicles class 8B	>60000	HDGV8B
20	Heavy-duty gasoline school bus	All	HDGSB
21	Heavy-duty gasoline transit bus	All	HDGTB
Diesel vehicles			
22	Heavy-duty diesel vehicles class 2B	8501-10000	HDDV2B
23	Heavy-duty diesel vehicles class 3	10001-14000	HDDV3
24	Heavy-duty diesel vehicles class 4	14001-16000	HDDV4
25	Heavy-duty diesel vehicles class 5	16001-19500	HDDV5
26	Heavy-duty diesel vehicles class 6	19501-26000	HDDV6
27	Heavy-duty diesel vehicles class 7	26001-33000	HDDV7
28	Heavy-duty diesel vehicles class 8A	33001-60000	HDDV8A
29	Heavy-duty diesel vehicles class 8B	>60000	HDDV8B
30	Heavy-duty diesel school bus	All	HDDSB
31	Heavy-duty diesel transit bus	All	HDDTB

APPLICATION OF MicroFacPM

The contribution to $PM_{2.5}$ emissions is discussed for Tuscarora Mountain Tunnel, Pennsylvania Turnpike, PA (scenario 1); and along Capital Boulevard Road in Raleigh, NC (scenario 2).

SCENARIO 1:TUSCARORA MOUNTAIN TUNNEL, PENNSYLVANIA TURNPIKE, PA

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 1.01 mi 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 of one hour duration except the last which was for a two hour duration. Average vehicle speed was determined using a radar gun. The detailed traffic fleet composition and age-wise distribution were determined visually on a run-by-run basis.[13,14] Tables 2 summarizes the traffic fleet data and speeds for 18 runs during the study period.

Table 2. Tuscarora Mountain Tunnel study during evaluation time

Run No.	Date	Day	Start Time	Flow (No.)	Speed (mi/h)	LD (%)
1	5/18/99	Tue	12:00	532	54.9	62.78
2	5/18/99	Tue	20:00	385	54.8	45.97
3	5/18/99	Tue	22:00	293	57.0	35.49
4	5/19/99	Wed	2:00	190	55.1	13.68
5	5/19/99	Wed	19:00	452	57.7	53.10
6	5/19/99	Wed	21:00	357	54.4	41.46
7	5/19/99	Wed	23:00	249	53.6	28.11
8	5/20/99	Thu	1:00	201	55.0	21.39
9	5/20/99	Thu	16:00	726	53.2	69.56
10	5/21/99	Fri	5:00	247	58.1	35.63
11	5/21/99	Fri	9:00	574	53.8	63.76
12	5/21/99	Fri	17:00	814	56.9	86.73
13	5/22/99	Sat	11:00	553	57.0	88.61
14	5/22/99	Sat	13:00	536	56.5	82.84
15	5/22/99	Sat	15:00	489	57.0	83.03
16	5/22/99	Sat	17:00	440	59.5	85.68
17	5/23/99	Sun	10:00	530	58.1	82.08
18	5/23/99	Sun	12:00	1678	61.7	83.19

The speeds varied from 53.2 to 61.7 mi/h and the percentage of LD (Light Duty) vehicles ranged from 13.7 to 88.6 percent. The age-wise distributions of the fleet per vehicle class for each run were known. The vehicles operated mostly in the hot-stabilized mode. The LD fleet consisted mostly of new vehicles, comprised of about 64 percent Tier 1 (1994+) vehicles (ranged from 50.0 to 68.8%), 35 percent Tier 0 (1981-1993) vehicles (ranged from 29.6 to 48.1%), and 1 percent Pre-1981 vehicles (ranged from 0.0 to 3.2%). For the distribution of LDGV, LDGT, LDDV and LDDT, we assumed national default values, i.e. 67.25, 32.01, 0.49 and 0.25 percent, respectively.

The yearly age distributions were available for heavy-duty vehicles except for classes 7 and 8, which were grouped into 1993+, 1991-93 and Pre-1990. In the absence of a precise split between class 8A and class 8B vehicles, we assumed the national average for the breakdown of class 8A and 8B vehicles, i.e. 30.2% class 8A vehicles and 69.8% class 8B vehicles. The age-wise distribution for vehicles classes 7 and 8 was grouped in to 1993+, 1991-93 and Pre-1990. The HD age-wise distribution for Run 4 (May 19, Wednesday, Start Time 2:00) could not be found, therefore we assumed an age-wise distribution for this run similar to Run 8 (May 20, Thursday, Start Time 1:00).

Observed Versus Modeled $PM_{2.5}$ Emission Factors

The following input values are required to run MicroFacPM:

- Date
- Time
- Vehicle fleet characteristics
- Ambient temperature
- Atmospheric relative humidity
- Average speed
- Cold mileage option (Yes or No)
- Fuel type (Oxygenated or Non oxygenated)
- Smoking vehicles percentage

MicroFacPM was run assuming that these were no smoking (not high emitting) vehicles in the fleet. In view of the large percentage of diesel heavy-duty vehicles in classes 7 and 8 (HDDV7, HDDV8A and HDDV8B) and vehicles that were operating in the hot-stabilized mode, MicroFacPM results will not be very sensitive to ambient temperature and relative humidity changes. Since the Tuscarora Tunnel is relatively flat, brake wear emissions are assumed to be negligible. A comparison of the observed emission factor and a calculated MicroFacPM emission factor is shown in Figures 2. Note the modeled emission factors do not include the re-entrained road dust. The average observed factor and MicroFacPM values are 100 and 97 mg/mi, respectively. The higher observed values (in comparison to MicroFacPM estimated values) may be due to presence of a few smoking vehicles in the fleet, which is not accounted for in running the model due to the absence of any specific information.

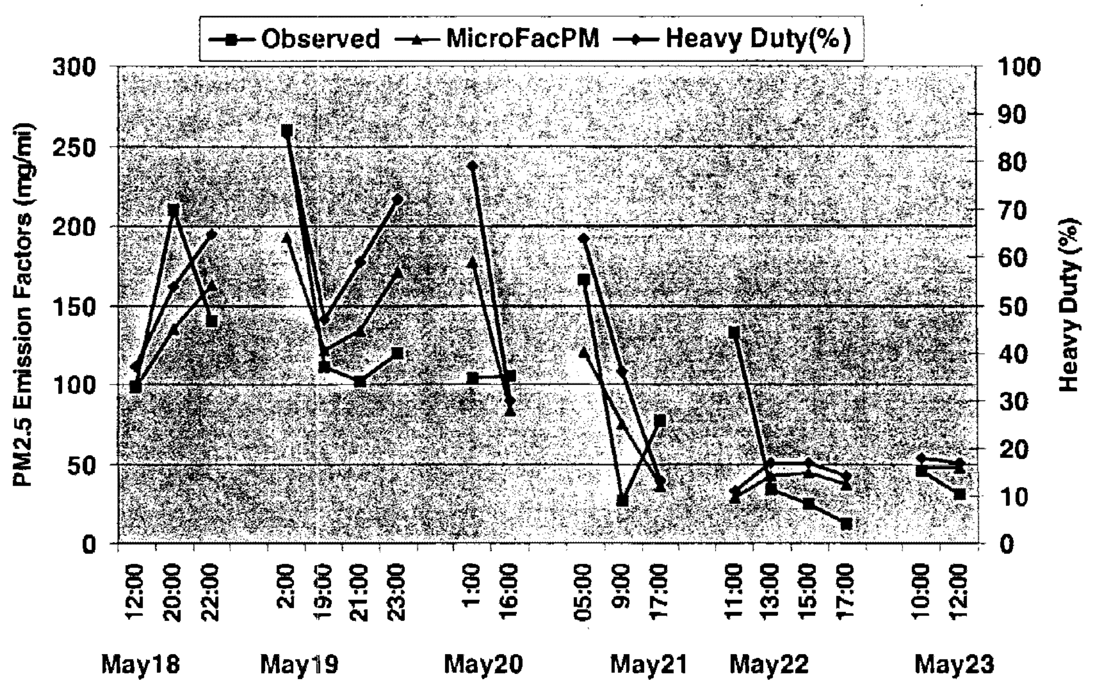


Figure 2. Comparison between the observed and MicroFacPM estimated PM2.5 emission factors for the Tuscarora Mountain Tunnel, PA in 1999.

Contribution of $PM_{2.5}$ Emission Factors by Vehicle Class

The contribution of emission factors for the MicroFacPM estimated values and percentage of vehicle classes are shown in Figure 3 and 4, respectively. The largest contribution of exhaust $PM_{2.5}$ came from the heavy-duty diesel vehicles in class 8B. If the fleet were dominated by light duty vehicles, then not only would the tailpipe emissions increase but tire wear emissions would also increase significantly.

The average contributions (average of 18 runs) of $PM_{2.5}$ emission factors are as follows: 2.4 percent from 58.7 percent LDGV&T, 2.9 percent from 0.4 percent LDDV&T, 0.04 percent from 0.8 percent HDGV, 3.6 percent from 1.5 percent HDDV45, 1.1 percent from 0.9 percent HDDV6, 14.7 percent from 6.5 percent HDDV7, 20.0 percent from 9.4 percent HDDV8A, 51.6 percent from 21.8 percent HDDV8B, and 3.7 percent from tire wear emissions.

The contribution of emissions ranged from 0.2 (Run 4) to 6.5 (Run 13) percent for LDGV&T, 0.2 (Run 4) to 8.3 (Run 13) percent for LDDV&T, 0.0 (Run 10) to 0.2 (Run 13) percent for HDGV, 0.0 (Run 7) to 9.0 (Run 15) percent for HDDV45, 0.2 (Run 7) to 3.7 (Run 6) percent for HDDV6, 6.6 (Run 2) to 28.6 (Run 17) percent for HDDV7, 13.4 (Run 13) to 24.2 (Run 7) percent for HDDV8A, 33.2 (Run 13) to 63.2 (Run 7) percent for HDDV8B and 1.9 (Run 4) to 7.5 (Run 13) percent for tire-wear.

Figure 3. Contribution of MicroFacPM estimated PM2.5 emission factors per vehicle class (including tire wear) for the Tuscarora Mountain Tunnel, PA in 1999.

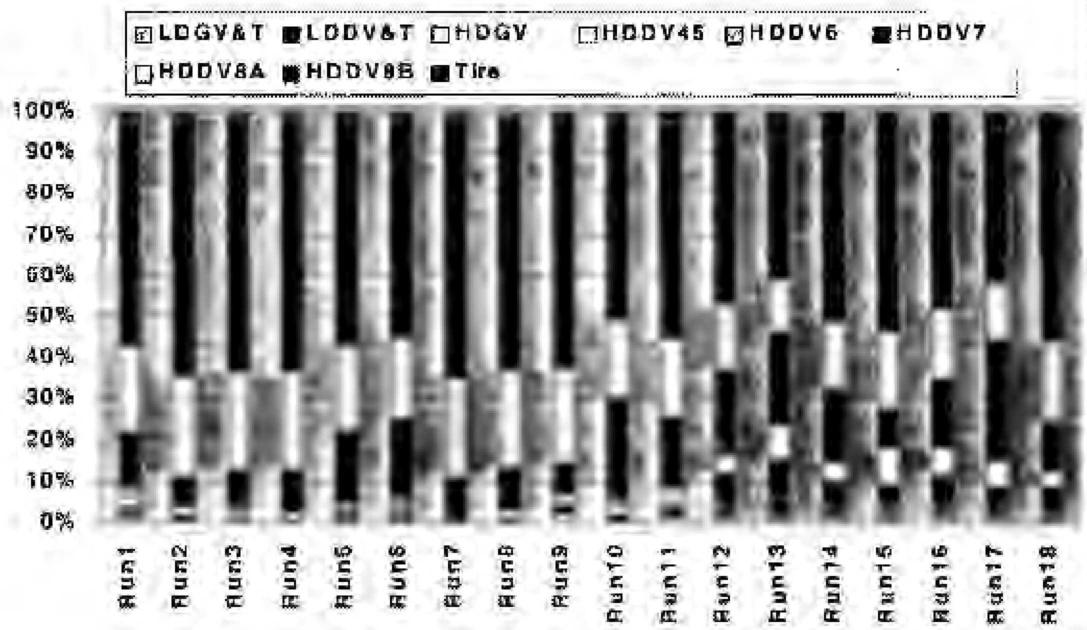
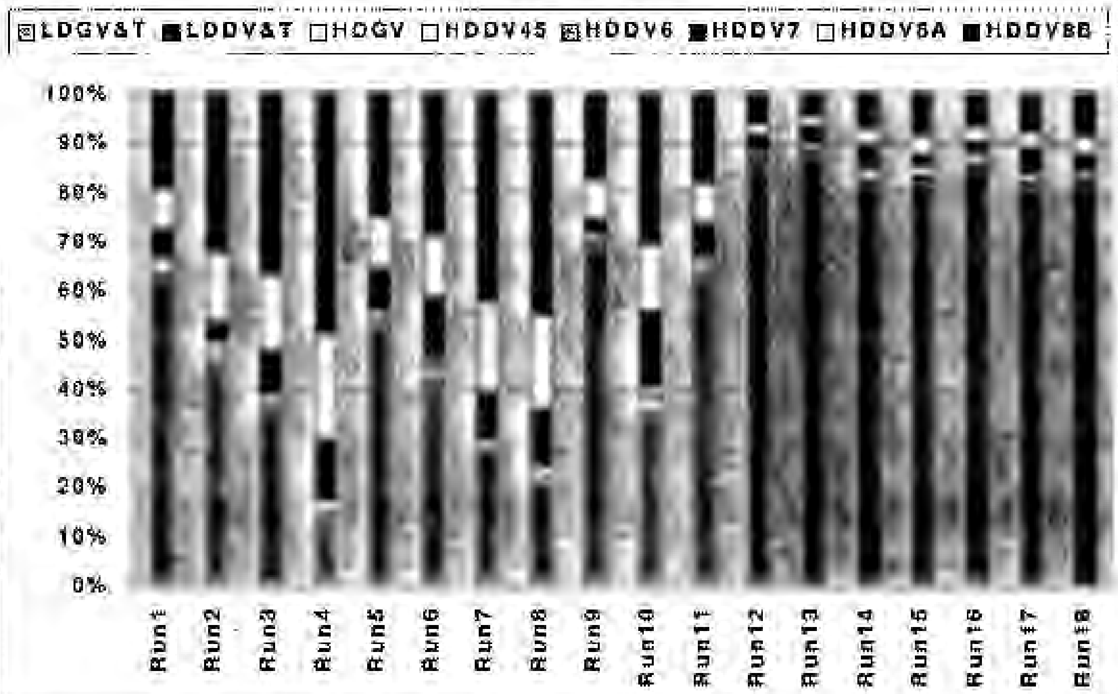


Figure 4. Percentage of vehicles for the Tuscarora Mountain Tunnel, PA in 1999



Contribution of $PM_{2.5}$ Emission Factors by Vehicle Age

In the Tuscarora Tunnel, the majority of $PM_{2.5}$ emissions came from heavy-duty diesel vehicles. The MicroFacPM emission rates for heavy-duty vehicles were derived from MOBILE6 sources and divided into mainly 1993+, 1991-93 and pre-1991 category. Therefore, the age-wise contribution of emission factors presented here is divided into three main categories. The contribution of emission factors for the MicroFacPM estimated values per age-wise and percentage of vehicle ages are shown in Figure 5 and 6, respectively.

The average contributions (average of 18 runs) of $PM_{2.5}$ emission factors for 1993+ vehicles, 1991-93 and pre-1991 are 37.9 from 69.3 percent vehicles, 39.5 from 19.7 percent vehicles and 22.6 from 11.0 percent vehicles, respectively.

The contribution of emissions ranged from 30.0 (Run 1) to 56.4 (Run 10) percent for 1993+ vehicles, from 18.9 (Run 11) to 48.6 (Run 3) percent for 1991-93 vehicles, and from 17.1 (Run 4) to 32.33 (Run 17) percent for pre-1991 vehicles.

Figure 5. Contribution of MicroFacPM estimated PM2.5 emission factors per vehicle age for the Tuscarora Mountain Tunnel, PA in 1999

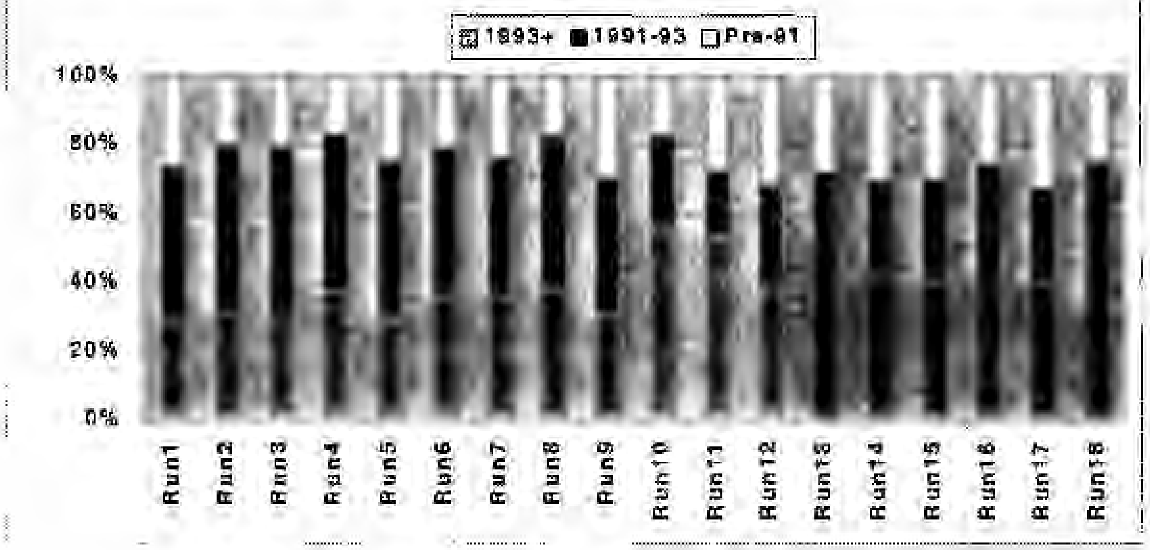
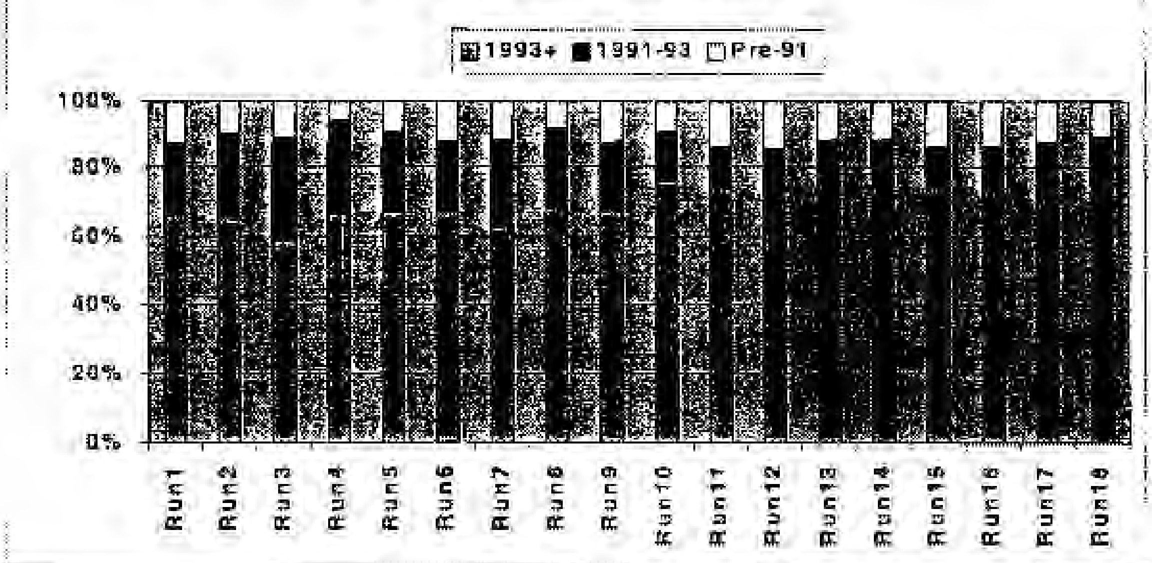


Figure 6. Percentage of vehicles per age for the Tuscarora Mountain Tunnel, PA in 1999



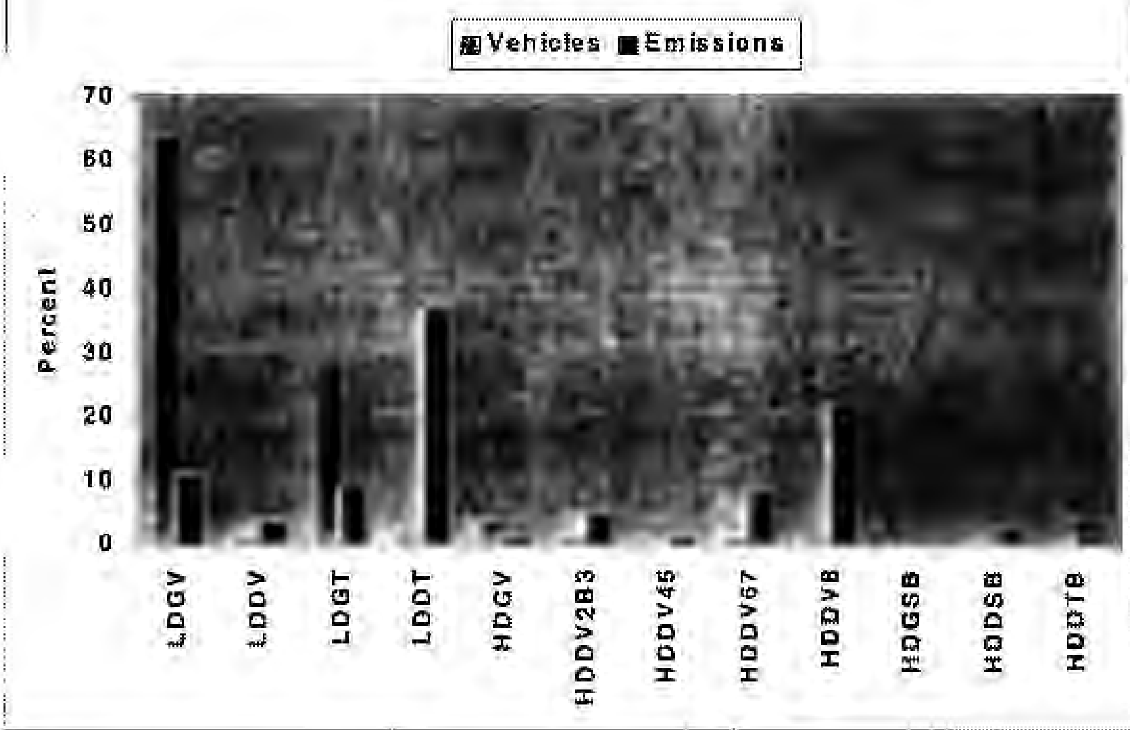
SCENARIO 2: CAPITAL BOULEVARD, RALEIGH, NC

In a test case, MicroFacPM was applied in conjunction with a line-source dispersion model, CALINE4, for a typical urban roadway setting to predict hourly average roadside concentration of $PM_{2.5}$.[15] The test case was run on Capital Boulevard in Raleigh, NC for 24 hrs staring at 8:00 AM on July 10, 2001. MicroFacPM was run with the cold mileage option, oxygenated fuel and the assumption of no smoking vehicles in the fleet. The light duty vehicle fleet composition and age-wise distribution for vehicles less than8500 lbs were assumed to be as registered in the Research Triangle Park area (Wake and Durham Counties), while for heavy-duty vehicle fleet (>8500 lbs) we used the average default US vehicle fleet.

Contribution of $PM_{2.5}$ Emission Factors by Vehicle Class

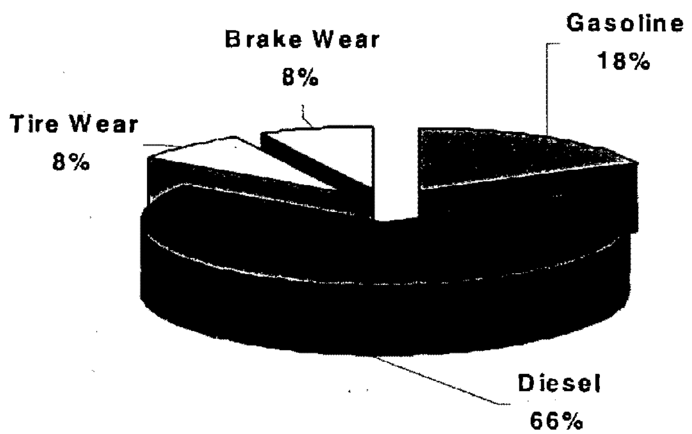
The average contribution of tailpipe $PM_{2.5}$ emission factors for the MicroFacPM estimated values and percentage of vehicle classes are shown in Figure 7. The largest contribution is from light-duty diesel trucks (37% emissions from 2% vehicles) followed by heavy-duty trucks class 8 (22% from 1% vehicles). About 92 percent light-duty gasoline vehicles and trucks (<8500 lbs) contributed only about 20 percent emissions.

Figure 7. Contribution of tailpipe PM2.5 emission factor per vehicle class



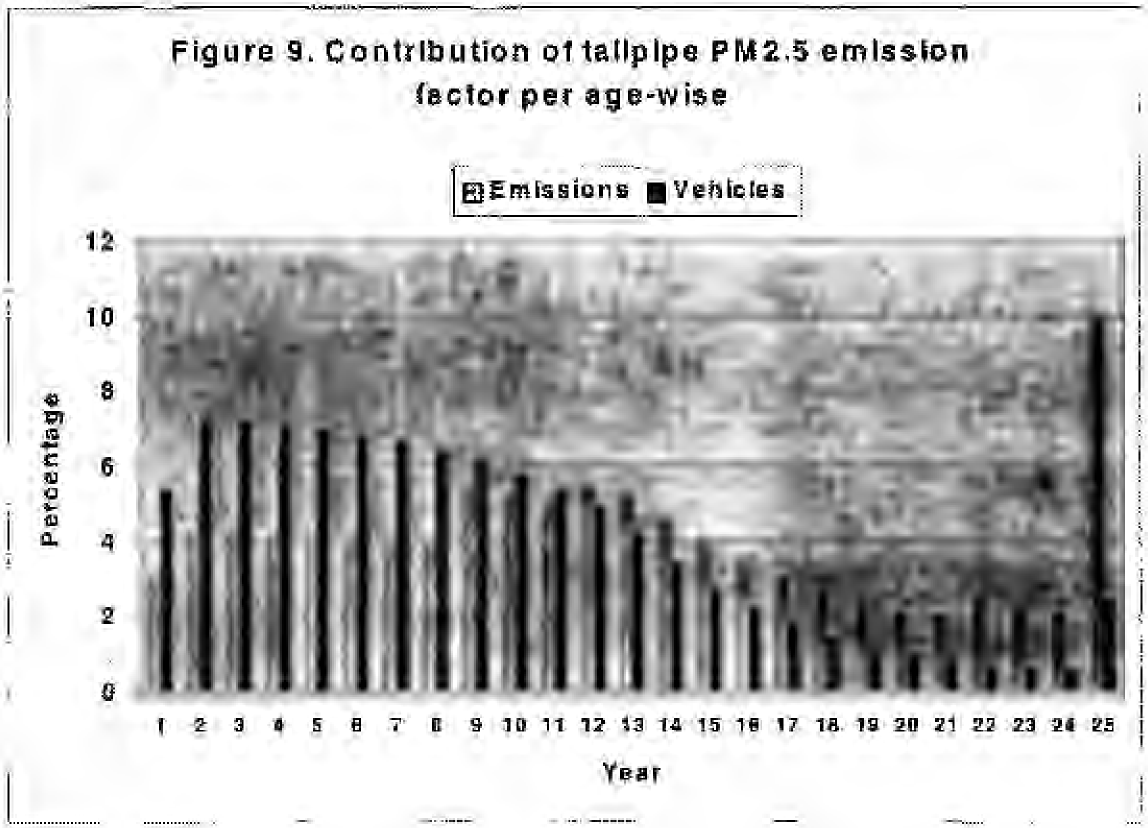
If we compare the contribution per source, then 66 percent of $PM_{2.5}$ emissions came from diesel vehicles, 18 percent from gasoline, 8 percent from tire wear and 8 percent from brake wear (Figure 8). Note that diesel vehicles comprised only 5 percent of the fleet. If during certain time intervals the traffic is relatively free flowing, then the brake wear emission factors can be accordingly reduced. This value was calculated for the typical urban driving cycle.

Figure 8. Contribution of PM2.5 emission factor per source



Contribution of $PM_{2.5}$ Emission Factors by Vehicle Age

Contribution to $PM_{2.5}$ exhaust emissions per age of the vehicle fleet is presented in Figure 9. The vehicles up to 5 year old constitute about 34 percent of the fleet, but contribute only 19 percent of the total exhaust $PM_{2.5}$ emissions, while vehicles more than 20 year old (5 percent of the fleet) contribute about 19 percent of total exhaust $PM_{2.5}$ emissions. Vehicles older than 15 years comprise about 87 percent of the fleet and contribute 67 percent of the total exhaust $PM_{2.5}$ emissions.



CONCLUSIONS

A microscale emission factor model for predicting real-world real-time motor vehicle particulate matter (MicroFacPM) emissions has been developed. MicroFacPM requires only a few input variables, which are necessary to characterize the local real-time fleet. MicroFacPM calculates the contribution of PM emissions from different vehicle categories and sources. MicroFacPM emission estimations are suitable for modeling air quality and human exposure in microenvironments near roadways.

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DISCLAIMER

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The United States Environmental Protection Agency's (EPA) National Exposure Research Laboratory is developing improved methods for modeling the source through the air pathway to human exposure in significant microenvironments of exposure. As a part of this project, we developed a microscale emission factor model for predicting real-world real-time motor vehicle particulate matter (PM_{10} and $PM_{2.5}$) (MicroFacPM) emissions, which uses available information on the vehicle fleet composition. This paper the use of MicroFacPM to calculate the contribution of $PM_{2.5}$ per vehicle class, age-wise, gasoline, diesel, brake wear and tire wear sources. The contribution of emission factors is presented for two scenarios: first the Tuscarora Mountain Tunnel, on the Pennsylvania Turnpike, PA ans second for Capital Boulevard, in Raleigh, NC. In the Tuscarora Tunnel, average contributions of $PM_{2.5}$ emission factors were 2.4 percent from 58.7 percent LDGV&T, 2.9 percent from 0.4 percent LDDV&T, 0.04 percent from 0.8 percent HDGV, 3.6 percent from 1.5 percent HDDV45, 1.1 percent from 0.9 percent HDDV6, 14.7 percent from 6.5 percent HDDV7, 20.0 percent from 9.4 percent HDDv8A, 5.16 percent from 21.8 percent HDDV8B, and 3.7 percent from tire wear emissions. For the Capital Boulevard, Raleigh, NC, scenario the largest $PM_{2.5}$ contribution was from light-duty diesel trucks (37% emissions from 2% vehicles) followed by heavy-duty trucks class 8 (22% from 1% vehicles).

17. KEY WORDS AND DOCUMENT ANALYSIS

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