Supporting Information for

Cost Effective Determination of Vehicle Emission Factors using On-Road Measurements

Neelakshi Hudda[1], Scott Fruin[1], Ralph J. Delfino[2] and Constantinos Sioutas[3*]

[1]Department of Preventive Medicine, Environmental Health Sciences, University of Southern California, Los Angeles CA 90089

[2]Department of Epidemiology, School of Medicine, University of California, Irvine, CA 92617

[3]Department of Civil and Environmental Engineering, University of Southern California, Los Angeles, CA 90089

*Corresponding Author Email: sioutas@usc.edu

Civil & Environmental Engineering
University of Southern California
3620 South Vermont Avenue
Los Angeles, CA, 90089
Tel: 213-740-6134
Fax: 213-744-1426

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S.1 Instruments used, sampling routes, days and meteorological conditions

Table S.1: Instruments used in this study

Instrument	Parameter measured	Instrument Flow Rate (L min^{-1})	Response Time (s)	Resolution	Detection Limit
TSI portable CPC (Ethanol-based) model 3007	UFP count, 10 nm - 1 um	0.8	<9 sec for 95% response	1 particle/cm^3	10 nm, <0.01 particles/cm^3
Magee Scientific Aethalometer AE 51	Black carbon (BC)	150 mL/min	~5	0.001 µg BC/m3	±0.1 µg BC/m^3, 1 min avg., 150 mL/min flow rat
LI-COR model LI-820	CO_2	1	<1	>4% of the reported value	3.0 ppm
2-B Technology Model 408	NO	1	8	Greater of 3 ppb or 3% of reading	
2-B Technology Model 401-410	NOx	1	8	Higher of 1.5 ppb or 2% of reading	
EcoChem PAH analyzer, model PAS 2000	Particle-bound Polycyclic Aromatic Hydrocarbons (PB-PAH)	2	< 10	~ 0.3 -1 g /m^3 PB-PAH per picoamp	3 ng/m^3
Garmin GPSMAP 76CSx	GPS location, speed	N/A	1	3 m	

Figure S.1: Freeway segments where measurements were conducted (generated using Google Maps).

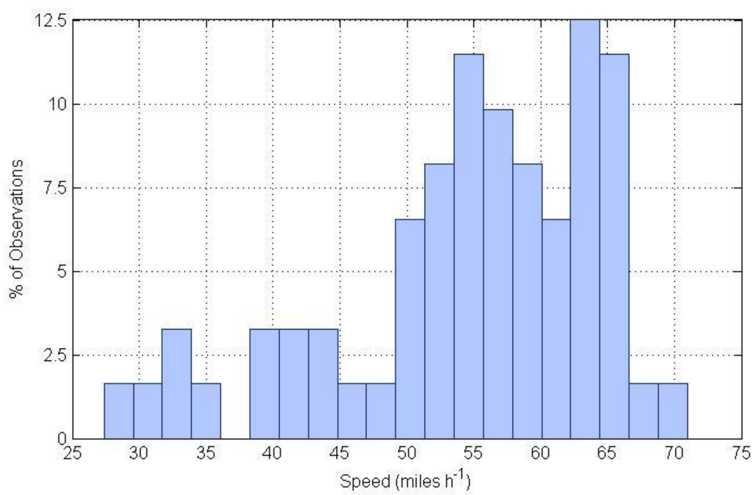

Figure S.2: Speed during runs on mixed-fleet freeways.

Table S.2: Sampling days, hours and meteorological conditions

Freeway	Hour	Date(MM/DD)	Temp	WS	WD
SR-110	6	06/8	16	2	SE
	7	05/20, 06/1, 06/8	19,21,16	1,2,2	N,N,S
	8	05/17, 05/20, 06/1	12,21,18	5,1,2	N,N,S
	9	06/2	21	5	W
	11	06/14	26	4	SW
	12	06/14	25	5	W
	13	06/3, 06/4	24,22	4,4	SW,S
	14	06/3	24	4	SW
	15	04/27	28	3	SW
	16	04/27	28	2	S
	18	01/25,	20	2	N
	19	05/30, 01/31	18,13	4,2	W,S
	20	01/25	17	2	N
	21	01/25	16	2	N
I-110	10	06/02,06/04	21,20	4,3	W,SW
	11	06/02,06/04	21,21	4,4	W,SW
	12	06/02,06/14	21,26	5,3	W,W
	13	06/02,06/14	22,25	5,3	W,W
	14	06/14	24	3	W
	16	06/01,06/15	19,22	5,3	W,W
	17	06/01	18	5	W
	18	06/01,06/15	16,18	4,3	W,W
SR-91	10	06/02,06/04	19,18	1,3	W,SE
	11	06/04	18	3	SE
	13	06/14	23	3	SW
	17	06/01,06/15	18,19	5,3	W,SW
	18	06/01,06/15	16,17	5,3	W,SW

Freeway	Hour	Date(MM/DD)	Temp	WS	WD
I-710	5	05/26,06/08	16,16	2,3	NE,S
	6	05/26,06/08	16,16	2,3	E,S
	7	05/26,06/02,06/08	18,19,17	1,1,3	SE,S,S
	8	05/26,06/02,06/08	18,19,17	2,1,3	S,S,S
	9	05/17,05/20	13,17	4,4	E,SE
	10	05/17,05/20,06/14	13,17	2,4	NE,S
	11	06/03,06/04	17,18	5,4	S,SW
	12	06/03,06/04	18,18	4,4	W,S
	13	06/03	18	4	SW
	14	06/03	19	5	S
	15	06/03	21	4	S
	18	05/30	20	3	NW
	19	05/30	17	3	W
	20	06/01	15	3	W
	21	05/19	15	1	SW
	22	05/19	14	2	N
I-405	10	06/02	19	1	W
	11	06/02,06/04	20,18	1,3	W,SE
	12	06/02	20	2	W
	13	06/14	24	3	SW
	14	06/14	23	3	SW
	16	06/15	19	3	SW
	18	06/01	18	5	W

January measurements were conducted in 2012. All other measurements were conducted in 2011. Temperature (Temp) is in degree Celsius, wind speed (WS) in miles h^{-1} and WD refers to wind direction.

S.2 Emission factor calculations

S.2.1 Heavy Duty Vehicle contribution apportionment

On other freeway links other than SR-110, the distribution of ratio of increase in pollutant concentration to CO_2 concentration from SR-110 was used to attribute the correct fraction to light-duty vehicles (LDVs), and the remainder was attributed to heavy-duty vehicles (HDVs). The following equations summarize the technique.

Equation S.1: Elevation in pollutant concentration due to diesel fuel combustion

$$\Delta\,[P]_d = \Delta\,[P] - \Delta\,[CO_2]_g \left(\frac{\Delta\,[P]_{SR\ 110}}{\Delta\,[CO_2]_{SR\ 110}}\right)$$

where $\Delta\,[CO_2]_g$ is the fraction of CO_2 attributed to gasoline and can be apportioned using Equation S.2 (below), which takes into account the difference in gasoline and diesel vehicle fuel economies, fuel density and carbon fraction.

Equation S.2: CO_2 Apportionment

$$\Delta\,[CO_2]_g = \Delta\,[CO_2]\left(\frac{(1-f_d)\times(\frac{1}{FE_g})\times\rho_g\times w_g}{(f_d)\times(\frac{1}{FE_d})\times\rho_d\times w_d + (1-f_d)\times(\frac{1}{FE_g})\times\rho_g\times w_g}\right)$$

where f_d represents the fraction of vehicles using diesel fuel, FE is the fuel economy (mile L^{-1}), ρ Is the density of fuel (kg L^{-1}), and w_g and w_d are the mass fraction of carbon in gasoline and diesel. f_d or f_{HDV} was calculated using

Equation S.3, where VMT_{HDV} and VMT_{LDV} are vehicle-miles traveled (VMT) by HDV (assumed to be completely diesel) and gasoline vehicles (assumed to be completely gasoline), during the measurement period on the freeway segment under consideration.

Equation S3: Fraction of fuel consumed that was diesel

$$f_{HDV} = \frac{VMT_{HDV}}{VMT_{HDV} + VMT_{LDV}}$$

The values for fuel economy used in this study were 5.1 miles L^{-1} and 2.0 miles L^{-1} for gasoline and diesel fuel engines, respectively, based on Los Angeles fuel usage figures. The input data for VMT and subcategory fuel economies was obtained from CARB EMFAC2011 emission rates inventory (EMFAC, 2011) (Table S3). Fuel density values were 0.74 kg L^{-1} and 0.84 kg L^{-1} for gasoline and diesel fuel, respectively, similar to other studies (Ban-Weiss et al., 2008)

S.2.2 Traffic Characterization

Many traffic related parameters (for example, speed, vehicle count, vehicle miles travelled per lane) are recorded at vehicle detection stations (based on single loop detectors) and reported by PeMS, a real-time traffic data tool made available by California Department of Transportation (CALTRANS) (Caltrans 2009). PeMS offers the advantage of obtaining HDV estimates at a much finer spatial resolution, since there are hundreds of detectors on a freeway, averaging approximately one every mile. In contrast, weigh-in-motion sensors (only one each is present on each side of I-710, I-405 and I-91 in Los Angeles) cannot provide the necessary spatial resolution needed to resolve real time pollutant data.

Overall, 53.4 % of VMT in LA are travelled using passenger cars, 23.9 % using light duty trucks and 13.2 % using medium duty vehicles. These three categories constitute LDV categorization in this study and are overwhelmingly fueled by gasoline engines. The remaining HDV VMT were assumed to be all diesel powered and to occur in the two right most lanes. PeMS assigns VMT_{HDV} based on an algorithm that takes vehicle-to-vehicle distance into account as opposed to axle weights and estimates truck traffic volume to within 5.7% of the values reported by weight-in-motion sensors (Kwon et al., 2003). A correction factor was applied to VMT_{HDV} estimates from PeMS on account of possible inability of PeMS to assign the light-heavy duty diesel truck (HDDT) correctly to HDV category. As much as 22% of HDDT VMT in LA results from light-HDDT, i.e., 40% of heavy-HDDT VMT, so a correction factor of 1.4 was applied to the VMT_{HDT}. The details of the VMT breakdown in Los Angeles County and correction factor calculations are presented in the following Table S.3.

Table S.3: EMFAC 2011 VMT distribution and PEMS correction factor calculations

Vehicle Type	Fuel Economy (miles/gallon) Fuel Type DSL	GAS	% of Total VMT in LA County - EMFAC 2011 Fuel Type DSL	GAS	Classification in this study	Fuel Type assumption in this study, based on Caltrans PEMS classification as trucks
PC	29.5	22.0	0.16%	53.21%	LDV	GAS
LDT	28.1	16.7	0.01%	23.86%	LDV	GAS
MDV	30.1	12.7	0.01%	13.20%	LDV	GAS
HDGT						
LHDGT	-	12.9	-	3.54%	LDV	GAS
MHDGT	-	12.3	-	0.31%	indeterminate	indeterminate
HHDGT	-	11.5	-	0.06%	HDV	DSL
HDDT				-		
LHDDT	19.0	-	0.99%	-	LDV	GAS
MHDDT	8.7	-	1.12%	-	indeterminate	indeterminate
HHDDT	5.6	-	2.32%	-	HDV	DSL
Other			0.68%	0.14%	none	none

Correction Factor Calculations

adjust for misclassification in HHDGT category		
HHDGT/HHDDT	2%	reduce HDV or truck VMT by multiplying by 0.98
adjust for misclassification in LHDDT category		
LHDDT/HHDDT	43%	increase HDV or truck VMT by multiplying by 1.43
Resultant Correction factor		1.4
Correction Factor applied on		PEMS classification as trucks, which is sum of HHDGT & HHDDT and an indeterminate fraction of MHDDT & MHDGT

FUEL EFFCIENCY USED IN THIS STUDY		DSL/HDV/Trucks	GAS/LDV/not truck
miles/gallon	VMT weighed average of PC, LDT & MDV category	7.4	19.2
miles/liter	VMT weighted average for HDDT	2.0	5.1

S.4 Vehicle Activity Trends on freeways

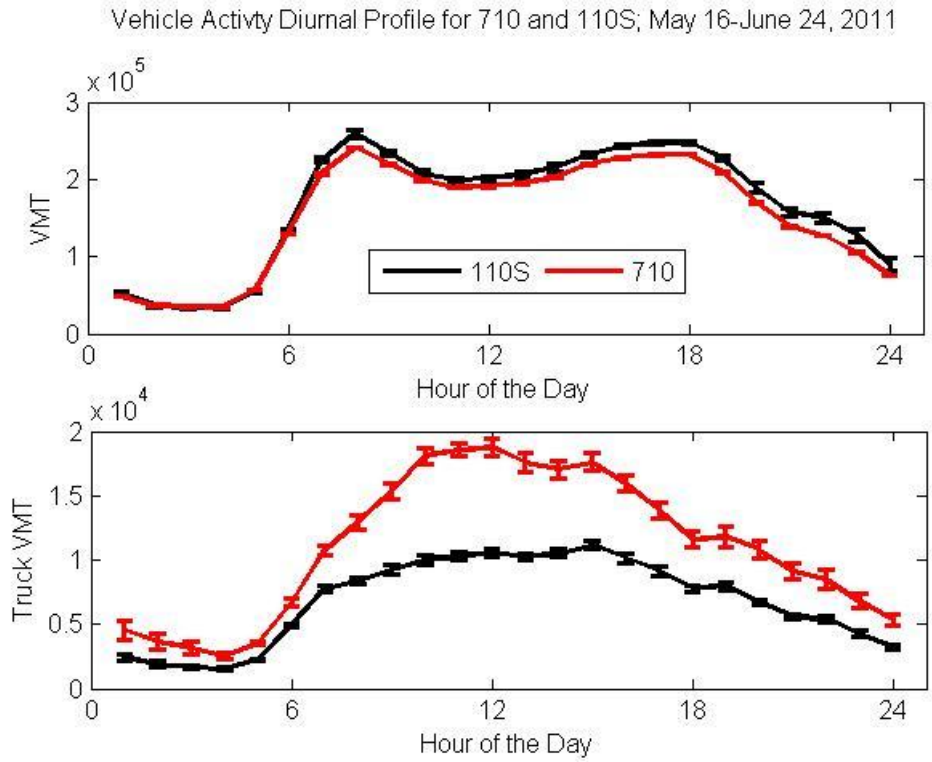

Figure S.3: Diurnal vehicle activity trend on two Los Angeles freeways, representative of general trend on all freeways.

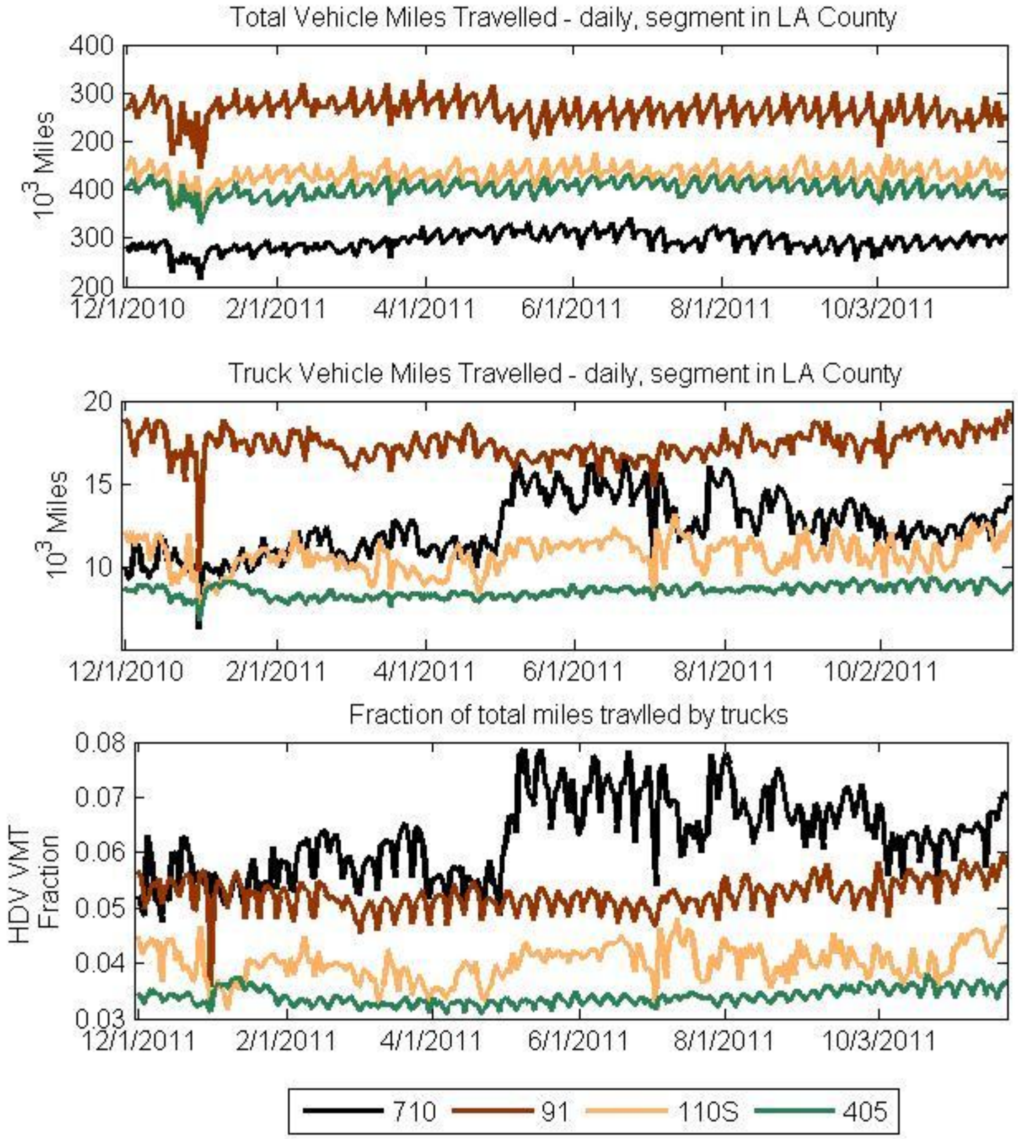

Figure S.4: Vehicle miles travelled, truck vehicle miles travelled and fraction of total miles traveled by truck on four Los Angeles freeways in LA County during 12/1/2010 – 30/11/2011.

References

Ban-Weiss, G.A., McLaughlin, J.P., Harley, R.A., Lunden, M.M., Kirchstetter, T.W., Kean, A.J., Strawa, A.W., Stevenson, E.D. and Kendall, G.R. (2008). Long-Term Changes in Emissions of Nitrogen Oxides and Particulate Matter from On-Road Gasoline and Diesel Vehicles. *Atmospheric Environment,42,* 220-232.

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