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A Fuel-Based Inventory for Heavy-Duty Diesel Truck Emissions

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ABSTRACT

A fuel-based method for estimating heavy-duty diesel truck emissions is described. In this method, emission factors are normalized to fuel consumption; vehicle activity is measured by the amount of diesel fuel consumed. For the San Francisco Bay Area during summer 1996, heavy-duty diesel trucks were estimated to emit 100×10^3 kg/day of NO_x and 6.4×10^3 kg/day of exhaust PM. These values were 2.1 and 1.8 times, respectively, the corresponding values predicted by California's motor vehicle emission inventory model, MVEI 7G. Significant decreases in diesel truck activity and emissions, 70-80% below typical weekday levels, were observed in the Bay Area on weekends. Reductions in diesel NO_x and black carbon (BC) particle emissions on weekends may contribute to higher ambient ozone concentrations and higher OC/BC ratios observed on weekends. Heavy-duty truck traffic peaks on weekdays during the middle of the day and falls off before the afternoon rush hour. Therefore, the diurnal pattern of heavy-duty truck travel may contribute to increases in ambient OC/BC ratios observed during late afternoon hours.

INTRODUCTION

In November 1996, the U.S. Environmental Protection Agency proposed a new National Ambient Air Quality Standard (NAAQS) for particulate matter with aerodynamic diameter of $2.5 \mu\text{m}$ or less, $\text{PM}_{2.5}$. Whereas the existing NAAQS for PM_{10} regulates particles generated both by mechanical and chemical processes, a $\text{PM}_{2.5}$ standard would

require greater emphasis on controlling combustion source emissions and gas-to-particle conversion in the atmosphere.

Heavy-duty diesel trucks (i.e., diesel-powered trucks with gross vehicle weight exceeding 3860 kg or ~4 tons) are an important source of fine particle and nitrogen oxide (NO_x) emissions.¹ Cass and Gray² estimate that during the 1980s heavy-duty diesel engines accounted for 70% of total fine black carbon particle emissions from on-road vehicles in the Los Angeles area. Current estimates from California's MVEI 7G motor vehicle emission inventory model for the San Francisco Bay Area indicate that in 1996 heavy-duty diesel trucks contributed 84% of exhaust PM emissions and 38% of total NO_x emissions from on-road vehicles.³

Motor vehicle emissions are currently estimated using the travel-based MOBILE⁴ and EMFAC⁵ emission factor models in the U.S. and California, respectively. In this approach, estimates of vehicle travel are combined with emission factors expressed on a mass per unit distance traveled basis to obtain a motor vehicle emission inventory.

Traditionally, vehicle activity has been estimated using travel demand models.^{6,7} Spatially- and temporally-resolved vehicle activity is predicted using socioeconomic data such as population, employment, automobile ownership, and income, combined with knowledge of travel times between points, available modes of transportation, and a description of the roadway network. Heavy-duty truck travel represents only a small fraction of total vehicle travel, so little effort has been made to describe truck travel explicitly within travel demand models.⁷ In current modeling practice it is common to estimate heavy-duty truck travel as a fixed percentage of predicted traffic volumes.⁷ However, as noted by Schlappi et al.⁸, heavy-duty truck travel does not follow the same

spatial and temporal patterns as light-duty vehicle travel. Consequently, heavy-duty truck activity estimates should not be based upon light-duty vehicle travel patterns.

Alternatively, measurements of vehicle kilometers of travel (VKT) for trucks may be used to estimate truck activity. In California, truck VKT is measured only on the state highway system, so reported truck VKT does not include all truck activity. However, truck VKT may be used in conjunction with statewide fuel sales to estimate total heavy-duty truck activity, using the amount of fuel consumed as a measure of activity. Accurate diesel fuel sales data are available at the state level, and truck VKT is measured and reported at the county level.⁹

Light-duty vehicle emissions are regulated per unit distance of travel. Likewise, current emission inventory models rely on emission factors expressed per mile or km traveled. In contrast, heavy-duty diesel truck emissions are regulated per unit of brake work output by the engine. Since heavy-duty trucks encompass a wide range of diesel engine sizes and gross vehicle weights, emission factors normalized to work output vary less than they would on a distance traveled basis. Furthermore, performance maps for heavy-duty diesel engines indicate that brake specific fuel consumption (bsfc) varies only slightly as engine operating conditions change. For example, Heywood¹⁰ presents the performance map for a 6.5 liter diesel engine. Over a wide range of operating conditions, bsfc varied from 220 to 260 g/kW•hr for this engine. Therefore, work output by the engine can be directly related to fuel input, and heavy-duty diesel engines are effectively regulated and designed to meet emission targets on a per unit of fuel burned basis.

Previous studies have already demonstrated the utility of a fuel-based approach for estimating light-duty vehicle emissions.^{11,12} As described by Singer and Harley¹¹ for

light-duty vehicles, the advantages of the fuel-based approach include the fact that fuel use data are readily available from tax records. Furthermore, emission factors normalized to fuel consumption vary considerably less over the full range of driving conditions than travel-normalized emission factors.^{11,13} The fuel-based methodology applied to heavy-duty diesel trucks provides the same advantages.

The objectives of this study are to: (1) describe and apply a fuel-based method for estimating heavy-duty diesel truck exhaust emissions of PM and NO_x; (2) compare fuel-based emission inventory estimates with California MVEI 7G model predictions; and (3) describe weekly and diurnal patterns of heavy-duty truck activity and compare these with light-duty vehicle activity patterns.

METHOD

A fuel-based emission inventory for heavy duty diesel trucks combines vehicle activity data (i.e., volume of diesel fuel consumed) with emission factors which are normalized to fuel consumption (i.e., mass of pollutant emitted per unit volume of fuel burned) to estimate emissions within a region of interest.

Vehicle Activity

At the statewide level, precise fuel consumption data are available through tax records.¹⁴

The reported statewide fuel consumption can be apportioned to provide emission estimates for an individual air basin by month, day of week, and time of day. Spatially- and temporally-resolved use of diesel fuel was estimated using the following equation:

$$A_{i,j,k,l} = \left(\frac{D}{365} \right) f v_i m_j d_k h_{k,l} \quad (1)$$

where $A_{i,j,k,l}$ is the amount of fuel burned in air basin i during month j , day of week k , and hour l ; D is the annual statewide volume of diesel fuel used by on-road vehicles; f is the fraction of on-road diesel fuel used by heavy-duty trucks; v_i is the fraction of statewide fuel use in air basin i ; m_j is the ratio of daily fuel sales in month j to annual average daily sales; d_k is the ratio of fuel used on day k to the average weekly value; and $h_{k,l}$ is the fraction of total fuel use on day k that occurs during hour l . Methods for estimating the parameters needed in Eq. 1 are described below.

Emission Factors

Currently, the EPA uses a transient engine dynamometer test to measure emissions from individual heavy-duty diesel engines.¹⁵ Emission factors obtained from engine dynamometer tests are reported in grams of pollutant emitted per unit of brake work

performed by the engine. These emission factors can be normalized to fuel consumption as follows:

$$EI_p = \left(\frac{s_p}{bsfc} \right) \quad (2)$$

where EI_p is the emission index for pollutant P, in units of mass of pollutant emitted per unit mass of fuel burned; s_p is the brake specific pollutant emission factor obtained from the dynamometer test, expressed in g/kW•hr units; and bsfc is the brake specific fuel consumption of the engine being tested, also in g/kW•hr. California exhaust PM and NO_x emission standards for heavy-duty diesel trucks are presented in Table 1; these standards correspond to s_p in Eq. 2 above.

Emission factors for heavy-duty diesel trucks also can be calculated from measurements of exhaust pollutant concentrations. Heavy-duty diesel trucks emit only small amounts of carbon monoxide and hydrocarbons.¹ Therefore, by carbon balance, the mass of diesel fuel burned can be directly determined from exhaust emissions of CO₂. An emission index EI_p for pollutant P can be calculated using:

$$EI_p = \left(\frac{\Delta[P]}{\Delta[CO_2]} \right) w_c \quad (3)$$

where $\Delta[P]$ is the exhaust concentration of pollutant P corrected for background levels and expressed in µg per m³; $\Delta[CO_2]$ is the exhaust concentration of CO₂ less background, expressed in µg carbon per m³; and w_c is the weight fraction of carbon in diesel fuel.

Vehicle Emissions

Exhaust PM and NO_x emissions are estimated by multiplying vehicle activity, as measured by the volume of fuel used, by emission factors expressed per unit volume of fuel burned.

APPLICATION

The methodology described above was applied to the San Francisco Bay Area for summer 1996. Fuel sales D for use in Eq. 1 were estimated from diesel fuel tax data by projecting 1985-1995 historic fuel sales data forward to 1996.¹⁶ The linear best-fit equation had a positive slope of 47,000 gallons per year and was used to estimate total diesel fuel consumption of 2.1×10^9 gallons in California for 1996.

In California, diesel fuel used by off-road vehicles is not taxed.¹⁷ Therefore, the value of D obtained from state tax records includes only diesel fuel used by on-road vehicles. MVEI 7G estimates indicate that for summer 1996 in the Bay Area, light-duty vehicles accounted for 4% of taxable diesel fuel use. Therefore, the parameter f in Eq. 1 was taken to be 0.96 (buses accounted for 6% of on-road diesel fuel consumption; this non-taxable fuel use was not included in the value of D described above).

The parameter v_i needed in Eq. 1 was estimated using the fraction of statewide heavy-duty diesel truck travel that occurs in the Bay Area. The California Department of Transportation (Caltrans) measures truck travel on the state highway system at statewide and county levels and reports travel data by axle class.⁹ The fraction v_i was computed by summing measured travel by trucks with 3 or more axles in the 9-county Bay Area, and dividing by the statewide total for the same classes of trucks. By this method, it was estimated that the Bay Area accounted for 12% of statewide total truck travel. However, for 2 of the 9 counties, only the urbanized portions are included in the Bay Area Air Basin. Together, these counties (Solano and Sonoma) accounted for 23% of measured Bay Area diesel truck travel. Truck travel estimates were adjusted to include only truck travel within urbanized areas of Solano and Sonoma counties. The final estimate for v_i used in Eq. 1 was 11%.

Monthly on-road diesel fuel sales data for California¹⁸ were used to quantify the seasonal variations in truck travel. Calculated values of m_j for 1993 varied from a low of 0.85 to a high of 1.23 with an average of 1.00 and standard deviation of 0.12. It appears

that some variations may be a result of fuel sales being reported quarterly, instead of monthly. In the present study, a uniform distribution of diesel fuel sales throughout the year was assumed (i.e., $m_j = 1.0$ in Eq. 1).

Hourly and daily truck counts at weigh-in-motion sites were used to determine d_k and $h_{k,l}$ in Eq. 1. Weigh-in-motion sensors consist of a magnetic induction loop and a pressure-sensitive bending plate, both of which are embedded in the roadway. The magnetic induction loop senses the presence of a vehicle and the bending plate measures weight per axle. By using the induction loop and bending plate together, it is possible to count passing vehicles and to classify the vehicles by weight and number of axles. Weigh-in-motion data for use in this study were provided by Caltrans for two heavily traveled Bay Area freeways: Interstate 880 in Hayward, and Highway 101 in Burlingame. Hourly vehicle counts from these sites for northbound and southbound traffic combined, were provided by axle class for a two-week period in summer 1996.¹⁹

To make use of the weigh-in-motion data, it was necessary to determine what fraction of vehicles counted in each axle class met the definition of a heavy-duty diesel truck. The 1992 Truck Inventory and Use Survey²⁰ was used to determine these fractions. Analysis of truck census data for California indicated that none of the 2-axle, 4-tire trucks surveyed were heavy-duty diesel; 43% of the 2-axle, 6-tire trucks were heavy-duty diesel; and >90% of all trucks with three or more axles were heavy-duty diesel.

The ratio of fuel used on day k to the average daily use of fuel, d_k in Eq. 1, was estimated as the average diesel truck count on day k divided by the average daily truck count for all days of the week combined. The fraction of total fuel use on day k that occurs during hour l , $h_{k,l}$ in Eq. 1, was estimated using the fraction of diesel truck counts from weigh-in-motion sites on day k that were measured during hour l .

Heavy-duty diesel truck emissions were measured at the Caldecott tunnel on Highway 24 between Oakland and Orinda, CA in summer 1996. The tunnel consists of three 2-lane traffic bores, with eastbound traffic running uphill on a grade of 4.2% at

moderate speeds of ~60 km/h. CO, CO₂, NO_x, and PM_{1.3} concentrations were measured in background air and inside the southernmost bore (bore 1) of the tunnel when heavy-duty diesel trucks accounted for ~5% of total traffic. Similar measurements were conducted in the center bore (bore 2) of the tunnel, where heavy-duty trucks accounted for <0.2% of total vehicles. All emissions in bore 2 were attributed to light-duty vehicles; ratios of each pollutant to CO in bore 2 were combined with measured CO concentrations in bore 1, to subtract the light-duty vehicle contribution from measured pollutant concentrations in bore 1. By this method, PM_{1.3} concentrations inside bore 1 of the tunnel were attributed almost entirely (~90%) to heavy-duty diesel trucks, whereas the same vehicles contributed ~50% of NO_x emissions in bore 1. Heavy-duty diesel trucks were estimated to contribute ~20% of CO₂ emissions in bore 1, based on visual traffic counts and fuel economy of 5 mpg for diesel trucks versus 20 mpg for light-duty vehicles. Emission indices of 2.6 ± 0.5 g of exhaust PM per kg of diesel fuel burned, and 44 ± 7 g/kg for NO_x were computed²¹ from measured pollutant concentrations at the Caldecott tunnel using Eq. 3. Emission factors used in this study were expressed per unit volume of fuel burned and computed by multiplying the above values by a typical density for diesel fuel of 0.83 kg/l.¹⁰

RESULTS

Weigh-in-motion traffic count data were analyzed to determine weekly and diurnal patterns in light- and heavy-duty vehicle activity. Daily total light-duty vehicle travel varied only slightly between weekdays and weekends, as shown in Figure 1. In contrast, diesel truck activity on weekdays was 128% of the weekly average, but dropped to 39 and 24% of weekly average values on Saturdays and Sundays, respectively.

Figure 2 shows the percent of daily total traffic occurring at each hour, separately for light-duty vehicles and for heavy-duty diesel trucks averaged over all five weekdays in the Bay Area. Light-duty vehicle traffic peaks during both the morning and evening rush

hours centered at 7 AM and 5 PM, respectively. In contrast, diesel truck traffic peaks around midday and falls to lower levels during the afternoon rush hour.

The fraction of weekday truck travel occurring during each hour was similar at both Bay Area weigh-in-motion sites, as shown in Table 2. Truck activity patterns observed in the Bay Area were similar to patterns observed in southern California at a weigh-in-motion monitoring site located on Interstate 710 in Long Beach (see Table 2).

The fuel-based emission inventory methodology described above was applied to calculate exhaust PM and NO_x emissions from heavy-duty diesel trucks in the Bay Area in 1996. Emission factors and activity data were combined to calculate the emission inventory presented in Table 3. The fuel-based inventory estimates for diesel truck NO_x and exhaust PM emissions on a typical weekday are 2.1 and 1.8 times, respectively, the corresponding MVEI 7G estimates.

DISCUSSION

Differences between MVEI 7G and fuel-based emission estimates arise in part because MVEI 7G does not account for the variation in truck travel between weekdays and weekends. However, after MVEI 7G emission estimates are increased to account for higher diesel fuel consumption on weekdays, the fuel-based inventory still differs from MVEI 7G estimates: NO_x emissions are 1.8 times, and exhaust PM emissions are 1.6 times, the corresponding MVEI 7G estimates. Consequently, uncertainty in emission factors also contributes significantly to the differences between fuel-based and MVEI 7G emission estimates. When compared to the emission factors derived from measurements at the Caldecott tunnel and used here in the fuel-based method, it appears that MVEI 7G uses lower emission factors for both NO_x and exhaust PM. While tunnel sampling reflects composite emissions from a large number of in-use trucks, the tunnel-derived emission factors may not be representative over the entire range of driving conditions found within the Bay Area.

A further source of uncertainty in comparing fuel-based emission estimates to those of MVEI 7G arises from differences in the definition of exhaust PM used in each calculation. This study uses PM_{1.3} emission factors to estimate exhaust PM emissions from heavy-duty diesel trucks. In contrast, MVEI 7G predicts exhaust PM₁₀ emissions. However, Eldering and Cass report that particles of aerodynamic diameter less than 1 µm account for ~91% of exhaust PM₁₀ from heavy-duty diesel trucks on a mass basis.²² Adjusting the MVEI 7G estimate to include only particles smaller than 1 µm reduces the predicted emissions of exhaust PM slightly to 3.2×10^3 kg/day, which increases the difference between fuel-based and MVEI 7G emission estimates.

Analysis of weigh-in-motion truck count data for the Bay Area revealed a sharp decline in heavy-duty vehicle travel on weekends which is clearly observable in Figure 1. The fuel-based emission inventory presented here highlights important differences between weekday and weekend emissions from diesel trucks. Decreases in off-road mobile source and stationary source activity may also contribute to weekday/weekend differences in air pollutant emissions. For example, decreases in emissions from off-road construction equipment on weekends could augment the emissions reductions from on-road diesel trucks.

Altshuler et al.²³ have reviewed ambient ozone concentrations for Northern California locations including the Bay Area, and report that on average, ozone concentrations are higher on weekends than on weekdays. Similar findings have been reported for other locations such as Los Angeles.^{24,25} Changes in heavy-duty diesel truck NO_x emissions between weekdays and weekends described in this study may contribute to the observed phenomenon of higher ozone concentrations on weekends. Heavy-duty diesel truck NO_x emissions in the Bay Area decrease relative to typical weekday conditions by ~70% and ~80% on Saturday and Sunday, respectively. Under California urban conditions, with low VOC to NO_x concentration ratios in ambient air, Altshuler et al.²³ argue that lowering NO_x emissions may lead to increased ozone concentrations.

Changes in exhaust PM emissions due to reduced diesel truck activity may lead to lower ambient fine particle concentrations on weekends. Since black carbon particles scatter and absorb light efficiently and are present in high concentrations in urban areas, they are an important cause of visibility impairment.²⁶ Therefore, reductions in exhaust PM emissions from diesel trucks may lead to improved visual range on weekends relative to typical weekday conditions.

Sensitivity analyses conducted on atmospheric photochemical mechanisms indicate that urban ozone formation is strongly influenced by the rates of NO₂ and formaldehyde photolysis.^{27,28} Therefore, because black carbon particles absorb light, ground-level sunlight intensity and photolysis rates may increase on weekends when black carbon particle concentrations are lower. Consequently, another contributing factor to the weekend effect may be that lower fine particle emissions from diesel trucks lead to increased photolysis rates and ozone formation on weekends.

The differences shown in Figure 2 between hourly activity patterns for heavy-duty diesel trucks and light-duty vehicles are consistent with findings reported for the Bay Area by Schlappi et al.⁸ The truck activity pattern is also consistent with weigh-in-motion truck count data from southern California shown in Table 2, and with reported truck activity patterns from other locations nationally.^{29,30}

Differences in the diurnal patterns of travel by light-duty and heavy-duty vehicles complicate the use of black carbon as a tracer for directly emitted organic carbon in secondary organic aerosol studies. Previous studies^{25,31,32} have used the ratio of ambient organic carbon (OC) to black carbon (BC) concentrations to estimate the contribution to OC from secondary organic aerosol formation. In such studies, a baseline OC/BC ratio is computed from known primary source emissions within the air basin. When the baseline ratio is exceeded in ambient air samples, the excess organic carbon is attributed to secondary organic aerosol formation.

Estimates of secondary organic aerosol formation based on changes in ambient OC/BC are uncertain because the proportion of vehicles that are diesel-powered and driving at a given hour varies throughout the day. Source tests^{33,34} have shown that the black carbon fraction of total fine carbonaceous particle emissions is higher in diesel exhaust than it is in gasoline exhaust. Hildemann et al.³³ report that black carbon accounted for 11 and 33% of fine carbonaceous particle emissions from non-catalyst and catalyst-equipped gasoline-powered vehicles, respectively, versus 55% black carbon in diesel engine carbon particle emissions. Likewise Watson et al.³⁴ report a lower black carbon fraction, 31% of total fine carbon particles, in gasoline engine exhaust compared to 45% black carbon in diesel engine exhaust emissions. Therefore, differences in the diurnal patterns of light- and heavy-duty vehicle activity may also contribute to variations in the ambient OC/BC ratio. As shown in Figure 2, diesel truck emissions fall off by mid-afternoon on weekdays, while at the same time, light-duty vehicle emissions are increasing. Therefore, the ratio of OC/BC in primary source emissions varies throughout the day.

Turpin and Huntzicker³¹ attributed increases in the OC/BC ratio in Los Angeles during a series of afternoons in summer 1987 to secondary organic aerosol formation. However, another contributing factor to the increases in OC/BC ratios may have been *decreased* BC emissions after ~3 PM when diesel truck activity drops off. Turpin and Huntzicker also reported weekend OC/BC ratios which were almost double the weekday ratios in August 1987. However, during the weekend days sampled, black carbon concentrations were lower than on weekdays, as expected due to lower weekend truck travel. Consequently, the elevated OC/BC ratio observed on weekends may be explained by changes in vehicle activity patterns.

CONCLUSIONS

A fuel-based approach to estimating emissions from diesel trucks was described and applied to the San Francisco Bay Area for summer 1996. Heavy-duty diesel trucks were

estimated to emit 100×10^3 kg/day of NO_x and 6.4×10^3 kg/day of exhaust PM on weekdays. Emissions declined by 70-80% on weekends. Weekday emissions of NO_x and exhaust PM were found to be 2.1 and 1.8 times, respectively, the predicted values from MVEI 7G.

Weekday/weekend differences in heavy-duty diesel truck travel and NO_x and exhaust PM emissions may contribute to the higher ambient ozone concentrations and higher OC/BC ratios observed on weekends. Furthermore, the decrease in heavy-duty diesel truck travel and peak in light-duty vehicle travel observed on weekday afternoons may contribute to increases in ambient OC/BC ratios observed during the afternoon hours.

The fuel-based method provides a useful, independent check on traditional travel-based emission inventory models. Improvements to the activity data underlying emissions estimates for heavy-duty diesel trucks have been described here. Emission inventories would benefit from further measurements of in-use heavy-duty diesel truck emissions. We encourage the measurement and reporting of fuel consumption in future emission factor studies so that the fuel-based emission inventory approach may be further developed.

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Table 1. California exhaust emission standards for heavy-duty diesel engines.³⁵

Model Year	NO _x	Particulate Matter
(g/bhp•hr) ^a		
1985-1986	10.7 ^b	—
1987-1990	6.0	0.60
1991-1993	5.0	0.25
1994-1996	5.0	0.10

^a In the United States, heavy-duty diesel engine emissions are regulated per unit of brake work output by the engine; standards are stated in g/bhp•hr units. Emission standards may be converted to g/kW•hr by multiplying the above values by a factor of 0.75.

^b Prior to 1987, a 13-mode steady-state test procedure was used which differs from the current transient test procedure.¹⁵ The NO_x standard in California was 5.1 g/bhp•hr under the old procedure. Sawyer and Johnson¹ estimate that this value is equivalent to 10.7 g/bhp•hr under current test procedures.

Table 2. Hourly heavy-duty diesel truck traffic counts as a percentage of the daily total diesel truck count for average weekday conditions.

	Interstate 880	Highway 101	Interstate 710
Time of Day (PDT)	Hayward	Burlingame	Long Beach
0000 - 0100 h	1.1 ± 0.3	1.4 ± 0.2	0.9 ± 0.2
0100 - 0200 h	1.0 ± 0.2	1.3 ± 0.1	0.9 ± 0.2
0200 - 0300 h	1.1 ± 0.1	1.4 ± 0.2	0.8 ± 0.2
0300 - 0400 h	1.4 ± 0.2	1.5 ± 0.1	0.9 ± 0.1
0400 - 0500 h	2.3 ± 0.1	1.9 ± 0.2	1.2 ± 0.1
0500 - 0600 h	4.2 ± 0.3	3.2 ± 0.1	2.3 ± 0.1
0600 - 0700 h	5.5 ± 0.5	5.7 ± 0.4	4.1 ± 0.2
0700 - 0800 h	5.4 ± 0.4	5.8 ± 0.3	5.2 ± 0.2
0800 - 0900 h	6.6 ± 0.3	6.8 ± 0.3	6.6 ± 0.2
0900 - 1000 h	7.8 ± 0.4	8.1 ± 0.5	8.1 ± 0.5
1000 - 1100 h	8.3 ± 0.2	7.9 ± 0.2	8.7 ± 0.4
1100 - 1200 h	8.0 ± 0.3	8.2 ± 0.5	9.2 ± 0.3
1200 - 1300 h	7.4 ± 0.2	7.4 ± 0.1	7.5 ± 0.2
1300 - 1400 h	7.2 ± 0.3	7.2 ± 0.3	7.6 ± 0.5
1400 - 1500 h	7.2 ± 0.3	6.7 ± 0.2	8.0 ± 0.3

1500 - 1600 h	5.7 ± 0.3	5.3 ± 0.3	7.2 ± 0.3
1600 - 1700 h	4.5 ± 0.2	4.3 ± 0.2	6.1 ± 0.1
1700 - 1800 h	3.4 ± 0.2	3.5 ± 0.2	4.1 ± 0.1
1800 - 1900 h	3.1 ± 0.3	2.9 ± 0.2	2.9 ± 0.2
1900 - 2000 h	2.5 ± 0.1	2.4 ± 0.3	2.4 ± 0.2
2000 - 2100 h	1.9 ± 0.2	2.1 ± 0.2	1.7 ± 0.2
2100 - 2200 h	1.6 ± 0.2	1.8 ± 0.2	1.6 ± 0.2
2200 - 2300 h	1.6 ± 0.3	1.9 ± 0.2	1.2 ± 0.2
2300 - 0000 h	1.3 ± 0.3	1.6 ± 0.4	1.1 ± 0.1

Table 3. Emission inventory for on-road heavy-duty diesel trucks in the San Francisco Bay Area, summer 1996.

	Fuel-Based Inventory			MVEI 7G	<i>Weekday Ratio:</i>
	<i>Weekday</i>	<i>Saturday</i>	<i>Sunday</i>	<i>Weekday</i>	<i>Fuel-Based to MVEI 7G</i>
Diesel Fuel Used (10^3 liters/day)	3000	910	570	2600	1.2
NO _x (10^3 kg/day)	100	33	20	48	2.1
Exhaust PM (10^3 kg/day)	6.4	2.0	1.2	3.5	1.8

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