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Analysis of heavy-duty diesel truck activity and emissions data

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Abstract

Despite their relatively small population, heavy-duty diesel vehicles (HDDVs) are (in 2005) disproportionate contributors to the emissions inventory for oxides of nitrogen (NO_x) and particulate matter (PM) due to their high individual vehicle emissions rates, lack of engine aftertreatment, and high vehicle miles traveled. Beginning in the early 1990s, heavy-duty engine manufacturers began equipping their engines with electronic sensors and controls and on-board electronic computer modules (ECMs) to manage these systems. These ECMs can collect and store both periodic and lifetime engine operation data for a variety of engine and vehicle parameters including engine speed and load, time at idle, average vehicle speed, etc.

The University of California, Riverside (UCR), under a contract with the California Air Resources Board (CARB), performed data analysis of 270 ECM data sets obtained from the CARB. The results from this analysis have provided insights into engine/vehicle operation that have not been obtained from previous on-board datalogger studies since those previous studies focused on vehicle operation and did not collect engine operating data.

Results indicate that HDDVs spend a considerable amount of time at high-speed cruise and at idle and that a smaller percentage of time is spent under transient engine/vehicle operation. These results are consistent with other HDDV activity studies, and provide further proof of the validity of assumptions in CARB's emission factor (EMFAC2002) model. An additional important contribution of this paper is that the evaluation of vehicle ECM data provides several advantages over traditional global positioning system (GPS) and datalogger studies: (1) ECM data is significantly cheaper than the traditional method (\$50 record^{-1} vs. $\sim$\$2000 record^{-1}) and (2) ECM data covers vehicle operation over the entire life of the vehicle, whereas traditional surveys cover only short periods of surveillance (days, weeks, or months). It is worthwhile to note that this work was not intended to compare the various methods of data collection but to provide additional empirical support for the EMFAC2002 model and to explore the utility of this unique low-cost form of data collection and analysis.

Keywords: Heavy-duty diesel; Vehicle activity; ECM; NO_x emissions; Driving activities; Emissions estimate

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1. Introduction

The California Air Resources Board (CARB) estimates that heavy-duty diesel vehicles (HDDVs) account for approximately 30% of the oxides of nitrogen (NO_x) and 65% of the particulate matter (PM) emitted by mobile sources while comprising only 2% of the on-road vehicle fleet in California (CARB, 2000). In many locations, HDDVs are major contributors to the overall emissions inventory, accounting for over 50% of the NO_x and PM emissions (Lloyd and Cackette, 2001; Yanowitz et al., 2000). These vehicles will continue to be a major contributor to the emissions inventory due to increases in goods movement and the high durability and reliability of the diesel engine. CARB has established a number of truck and bus classes based on gross vehicle weight, including six HDDV classes, as shown in Table 1. The NO_x emissions from these categories, calculated with EMFAC2002, are dominated by heavy-heavy-duty diesel trucks (HHDDTs).

EMFAC (EMission FACtor) (current version is 2002) is CARB's on-road motor vehicle emission factor model that has been approved by the US Environmental Protection Agency (EPA) for use in the State Implementation Plan (SIP) development and conformity processes in California. The model reflects current vehicle emissions test data, fleet demographic data, and planning information affecting vehicle emissions estimates. For each pollutant, a composite emission factor is the sum of each of the model-year-group average emission factors weighted by the travel fraction for each model-year-group. The model-year-group average emission factors are developed based on results from chassis dynamometer emissions tests. The vehicle miles traveled (VMT) estimates, and VMT speed distributions (i.e., the percent of VMT spent at any particular vehicle speed) come from the California Department of Transportation, travel demand models, and CARB staff analyses. The composite emission factors distill the emissions contributions from all model year vehicles in particular weight class (e.g., HHDDTs, T7) into a single set of values (composite emission factors by speed) that can then be multiplied by the corresponding speed-distributed VMT. In EMFAC2002, the emissions data set for HHDDTs is rather limited but will be expanded considerably with the release of EMFAC2005. Compared to VMT, vehicle population is not particularly useful to predict NO_x emissions because of differences in operating modes between the vehicle classes. For example, although the population of medium-heavy-duty diesel trucks (MHDDTs) equals that of the HHDDTs, their total NO_x emissions are only 27% of those emitted by HHDDTs because VMT for HHDDTs is much higher.

Although several studies have been conducted or are on-going to evaluate the emission rates of the existing HHDDT fleet, the current state of knowledge on the correlation between vehicle activity and total emissions is limited. Battelle (1999) used a global positioning system (GPS)-based approach to record the actual location of 140 heavy-duty trucks (HDTs), drawn from a volunteer sample from the California trucking industry, while in operation. These data have been used to develop chassis dynamometer emissions test cycles for HHDDTs and medium-heavy-duty trucks (MHDTs). Emissions data collected using these test cycles will be used to update both the emissions rates and speed correction factors in the EMFAC model.

Modern diesel engines have electronic computer modules (ECMs) that govern engine operation and allow manufacturers to optimize engine controls to improve fuel efficiency, which in turn affects

Table 1
California heavy-duty diesel vehicle classes

Category	Class	Weight (lb)	Population	VMT/1000 (mile)	NO_x emission rate in California (ton day^{-1})[a]
Light-heavy-duty diesel trucks 1	T4	8,501–10,000	26,607	1567	12.23
Light-heavy-duty diesel trucks 2	T5	10,001–14,000	33,544	1902	14.67
Medium-heavy-duty diesel trucks	T6	14,001–33,000	160,715	9157	142.42
Heavy-heavy-duty diesel trucks	T7	33,001	158,200	23,145	536.08
School buses	SB	All	18,800	765	12.42
Urban buses	UB	All	15,100	1789	49.06

[a]EMFAC2002, California Air Resources Board @ Year 2000.

emissions. Vehicle ECMs also maintain a log of various operating parameters such as vehicle speed and engine RPM to be used as a diagnostics and monitoring tool for fleet operators and maintenance shops. This feature is often useful in determining if warranty repair service will be approved. A large number of parameters are available from the ECM downloads of electronically controlled engines. In this paper, we show that this downloadable data set is a satisfactory and low cost ($50 record^{-1}) alternative to the traditional and labor-intensive (i.e., more expensive) means of obtaining information on activity for different portions of the HDDV fleet.

In this work, approximately 270 ECM downloads from in-use HDDVs were obtained by CARB through a private contractor. The specific data available from the ECM varies by manufacturer, but generally includes engine identification and vehicle operating summaries as well as information on the current engine control program and the vehicle activity record. Statistical analysis of the data yielded various characteristics of the on-road fleet as well as a means to estimate the contribution of these vehicles to the NO_x emissions inventory.

2. Experimental method

2.1. Description of database source

A data set consisting of ECM downloads from over 300 HDDVs was collected between late 2001 and early 2002, during the development of CARB's Measure 17 (M17) program. The M17 program is one component of the emission-reduction strategies developed for California's SIP for ozone. Specifically, the M17 program is designed to detect excess NO_x emissions from on-road HDDVs that are caused by lack of, or mal-maintenance. Vehicle ECMs were downloaded (into printed form) as they were turned into a used-truck dealer for sale. Therefore, these downloads provided the entire operating activity of the trucks before they entered the used-truck market. Only a single opportunity existed for each download. These electronic inspections represent a grab sample of data from the three major heavy engine manufacturers: Caterpillar, Cummins and Detroit Diesel.

2.2. Database construction

The data sheets obtained by the CARB were entered into a Microsoft Access database using standardized entry forms for each of the three manufacturers. The variables entered for each of the three manufacturers are listed in Table 2. Variable names differed somewhat from manufacturer to manufacturer. Individual model years also differed within manufacturers, and not all vehicles within each manufacturer had all of the listed variables.

In this study, only 270 downloads were identified as acceptable records, with the remaining 30 records or so eliminated due to poor print quality. In addition, for unknown reasons, some parameters in the data sheets were obviously unrealistic (e.g,. average vehicle speed in excess of 150 mph, which is significantly greater than the expected top speed of a commercial HDDV). Therefore, due to the potential effects of these unrealistic and illogical data on the statistical analysis, these data were flagged as outliers and the entire corresponding downloads were excluded from the final analysis.

Table 2
Variables entered into database for Caterpillar, Cummins, and Detroit Diesel

Parameter	Caterpillar	Cummins	Detroit Diesel
Vehicle no.	√	√	√
Date	√	√	√
Manufacturer	√	√	√
Engine model	√	√	√
VIN	√	√	√
Engine serial no.	√	√	√
ECM serial no.	√	√	√
Advertised power	√	√	√
Governed speed	√	√	√
Peak torque	√	√	√
RPM at peak torque	√	√	√
Total time	√	√	√
Total distance	√	√	√
Total fuel used	√	√	√
Total fuel economy	√	√	√
Total idle fuel	√	√	√
Total idle time	√	√	√
Average vehicle speed	√	√	√
Max. vehicle speed	√	√	√
% Time at idle	√	√	√
Total PTO fuel	√	√	√
Total PTO time	√	√	√
% Time at PTO	√	√	√
Total cruise time			√
% Time at cruise			√
Total brake time			√
Avg. load factor	√		
Brake actuations per 1000 miles		√	

2.3. Engine properties

Initial statistical analysis focused on basic descriptive statistics of the vehicle fleet. Summary statistics were compiled for all three manufacturers together with common variables and variables available only for specific vehicles. A summary of vehicle properties broken down by manufacturer is presented in Table 3.

Engine model year was identified based on VIN codes of the vehicles. Most of the vehicles in this study were manufactured between 1995 and 2000. A portion of the vehicles had missing or incomplete VIN codes, which prevented identification of the engine model year. Only 182 of the 270 vehicles had model year information on file.

Table 3 also presents engine families of each manufacturer that was involved in this study. Based on the results of analysis of variance (ANOVA) applied to advertised power and peak torque, on average, Detroit Diesel (440 ± 6 hp, 1502 ± 11 ft lb) vehicles have higher engine output than Caterpillar (401 ± 13 hp, 1435 ± 50 ft lb) and Cummins (344 ± 6 hp, 1289 ± 28 ft lb) vehicles. The Cummins vehicle fleet was also identified as having the smallest engine size in this study. This finding was also confirmed by the distribution of engine advertised power shown in Table 3.

Table 3
Summary of engine properties

	Caterpillar		Cummins		Detroit Diesel	
Count	72		108		90	
Model year	<1995	3	<1995	5	<1995	0
	1995	2	1995	5	1995	9
	1996	5	1996	13	1996	7
	1997	4	1997	18	1997	12
	1998	5	1998	20	1998	16
	1999	4	1999	14	1999	11
	2000	15	2000	8	2000	2
	>2000	1	>2000	2	>2000	1
	Total	39	Total	85	Total	58
	Unknown	33	Unknown	23	Unknown	32
Engine model	3126B	11	98 N14-*	4	6067BK60	7
	3176B	4	ISB 19*	9	6067GK60	43
	3406C	1	ISM 330	2	6067GU60	1
	3406E	45	M11-*	53	6067MK60	1
	C10	4	N14-*	35	6067PK60	8
	C12	7	STA-15	2	6067SK60	5
					6067TK60	13
					6067WK60	3
					6067WU60	3
	Total	72	Total	105	Total	84
	Unknown	0	Unknown	3	Unknown	6
Advertised power (hp)	<200	10	<200	9	<200	0
	250	0	250	0	250	0
	300	1	300	8	300	0
	350	4	350	26	350	1
	400	12	400	40	400	13
	450	17	450	13	450	41
	500	18	500	4	500	10
	550	4	550	0	550	20
	600	3	600	0	600	0
	650	2	650	0	650	0
	>650	0	>650	0	>650	1
	Total	71	Total	100	Total	86
	Unknown	1	Unknown	8	Unknown	4

3. Results and discussion

3.1. Vehicle operating characteristics

A summary of the vehicle operating characteristics is shown in Table 4. Data in Table 4 were analyzed by manufacturer and for the overall population. For example, the population data show that the distance traveled ranged from 12,648 to 1,032,566 miles, and the overall average was 392,975 miles. For these data, the standard deviation was 192,680 miles and the coefficient of variation was 0.49. These mileages are lower than most trucks would need for an in-frame overhaul; hence, suggesting an economic break point where the first owner liquidates a truck into reuse in the used-truck market. In other words, when a truck reaches 390 K miles (give or take nearly 200 K miles), the truck is sold and enters the used-truck market.

The level of detail available for operating parameters varied from manufacturer to manufacturer, with Caterpillar and Detroit Diesel providing activity data broken down by RPM and vehicle speed, while Cummins did not provide data in such detail. All vehicles did provide general data such as total operation time, distance traveled, and amount of fuel used, which allowed for the calculation of fuel economy.

3.1.1. Analysis of fuel economy data

Average calculated fuel economy varied from year to year within the vehicles sampled in this study (Table 4 and Fig. 1). The average of 6.6 mpg is reasonable and is consistent with other published information (Clark et al., 2002; Lev-On et al., 2002). The standard deviation was 1.1, yielding a coefficient of variation of approximately 17%. The relatively narrow distribution of fuel economy values can be seen in the histogram of Fig. 1. It is worth noting that the average fuel economy of the Cummins vehicle fleet was determined to be higher (at a statistically significant level) than that of the Caterpillar and Detroit Diesel fleets. This is consistent with the previous observation (Section 2.3) that the Cummins vehicle fleet has a smaller engine size.

3.1.2. Analysis of activity data

For the Caterpillar equipped vehicles, activity data were available on a basis of percentage of time that the vehicle was operated within discrete bins of vehicle speed (mph)/engine speed (rpm). In total, activity data were collected for 40 Caterpillar vehicles; 10 were 3126B engines and 30 were 3406E engines. The 3126B engines are primarily used in light cargo haulers and delivery trucks, while the 3406E engines are primarily used in large HHDDTs for transporting goods.

A summary of engine specifications of these 40 3126B and 3406E engines is provided in Table 5. Plots were constructed for the percentage of time that each engine spent at each vehicle speed/engine speed bin. Examination of the plots showed that 22 of the 30 Caterpillar 3406E engines showed only one significant peak, characteristic of high-speed operations. Fig. 2a is an example of an engine with a single peak. Fig. 2b shows a histogram of all of the Caterpillar 3406E single-peak vehicles. The numeric values in the legend in this histogram represent the possibility of the vehicle having an event in each operating region from none (marked as 0) to high (marked as 5). These results indicate that for this type of engine, there is almost no operating time at low-speed modes as high-speed operation dominates the activity record.

It is important to note that these activity plots, based on ECM downloads, only include activities with vehicle and engine speed above zero; in order words, the true idling mode (vehicle speed equal to zero and non-zero engine speed) is not included. Information on vehicle idle time is provided in the ECM downloads as a separate field, but it is not included with the information on vehicle speed/engine speed.

The remaining eight Caterpillar 3406E engines show two operating modes, with one peak (~47% of the total time) in the idling/low-speed driving region and the second peak (~53% of the total time) corresponding to the same high-speed operating region as the other 22 engines. An example of an engine with two operating peaks is presented in Fig. 3a. Fig. 3b shows a histogram of all of the Caterpillar 3406E vehicles with two peaks.

As previously mentioned, 10 of the Caterpillar engine equipped vehicles used a Caterpillar 3126B engine. The data from these engines exhibited an activity pattern dispersed over a larger operating envelope than the 3406 engines (low power:transient:high power ratio = 48:36:16). This is indicative of intra-city driving and would be characteristic of delivery trucks. An example of this usage pattern is provided in Fig. 4a, and the histogram analysis plot of all of the Caterpillar 3126B vehicles is shown in Fig. 4b.

Table 4
Summary of vehicle operating characteristics

		Total time (h)	Total distance (mile)	Total fuel used (gal)	Total fuel economy (mpg)	Total idle fuel (gal)	Total idle time (h)	% Time at idle	Total PTO fuel (gal)	Total PTO time (h)	% Time at PTO	Total cruise time (h)	% Time at cruise	Total brake time (h)	Advertised power (hp)
Total fleet	Max	30264	1032566	160419	10.4	26444	20264	68.4	7912	12337	57.7	7029	46.1	1213	675
	Min	612	12648	1657	3.5	4	5	0.1	0	0	0.0	130	1.2	11	190
	N	247	255	253	252	252	252	244	250	253	246	84	84	76	257
	Ave	12679	392975	62284	6.6	2233	4204	29.4	704	1313	9.2	2670	18.4	325	391
	SD	6246	192680	33034	1.1	2722	3909	18.7	1243	2286	13.5	1564	9.0	237	85
	COV	0.49	0.49	0.53	0.17	1.22	0.93	0.64	1.77	1.74	1.47	0.59	0.49	0.73	0.22
Detroit Diesel	Max	30264	859797	146210	7.6	26444	17475	64.9	4899	12118	45.1	7029	46.1	1213	675
	Min	2893	59023	10716	4.0	209	536	4.3	2	3	0.0	130	1.2	11	315
	N	86	86	86	86	85	85	85	84	85	85	84	84	76	86
	Ave	14772	452889	71821	6.4	2672	6456	42.9	1366	2856	18.8	2670	18.4	325	439
	SD	5900	165400	27780	0.6	2980	3858	13.6	1209	2534	13.3	1564	9.0	237	54
	COV	0.40	0.37	0.39	0.09	1.12	0.60	0.32	0.89	0.89	0.71	0.59	0.49	0.73	0.12
CAT	Max	29634	926059	160419	7.7	15313	20264	68.4	1260	433	4.9				600
	Min	612	12648	1657	3.5	20	33	0.7	0	0	0.0				190
	N	62	70	68	67	68	68	60	69	70	62				71
	Ave	12775	391312	67614	6.0	3549	5302	33.3	31	11	0.2				401
	SD	7768	230146	41290	0.9	3088	4074	17.8	156	57	0.8				107
	COV	0.61	0.59	0.61	0.15	0.87	0.77	0.53	5.07	5.25	5.10				0.27
Cummins	Max	21363	1032566	156551	10.4	8274	7829	56	7912	12337	58				460
	Min	1521	34799	3623	3.6	4	5	0.1	0	0	0.0				190
	N	99	99	99	99	99	99	99	97	98	99				100
	Ave	10802	342106	50337	7.2	953	1517	15.6	610	905	6.6				342
	SD	4770	171568	26969	1.2	1348	1580	12.7	1418	2130	12.9				62
	COV	0.44	0.50	0.54	0.17	1.41	1.04	0.82	2.32	2.35	1.96				0.18

Max: maximum; Min: minimum; N: count; Ave: average; SD: standard deviation; COV: coefficient of variance; PTO: power take off.

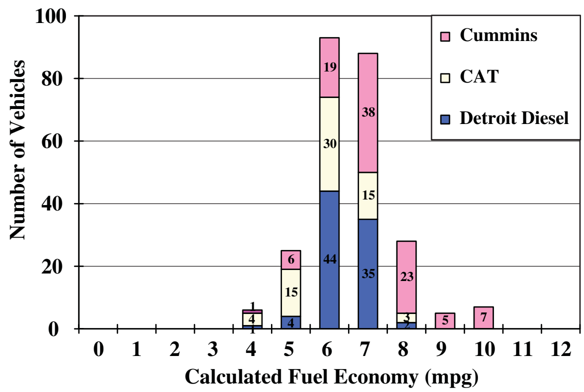

Fig. 1. Histogram of calculated fuel economy.

Table 5
Engine specifications of Caterpillar 3126B and 3406E in this study

		3126B	3406E
Advertised power	hp	190–251	355–600
Governed speed RPM	rpm	2200–2300	1800–2100
Displacement	liter	7.2	14
Peak torque	lb ft	520–660	1350–2050
RPM @ peak torque	rpm	1440	1200–2120
No. of cylinders		6	6
Turbo	Y/N	Y	Y

The distribution of VMT for these 40 Caterpillar vehicles can be seen in Fig. 5. The VMT data is further parsed to indicate whether the vehicle activity data showed one, two, or a distribution of operating peaks. All ten 3126B engine vehicles have low VMT (<50 K miles, defined as "short-haul/in-city" use pattern). The eight Caterpillar 3406E vehicles with two activity peaks had a moderate amount of mileage accumulation (100 K miles <VMT<300 K miles, defined as "medium-haul/intercity" use pattern). The remaining 22 Caterpillar vehicles with a single activity peak primarily display a high VMT (one vehicle was relatively new, VMT <100 K miles). The high VMT value (>300 K miles, defined as "long-haul" use pattern) is characteristic of long-haul vehicles. The driving mode distribution/VMT presented in Fig. 5 could be applied as another reliable indicator of HDD vehicles activity to determine what emission factor weighting should be used to estimate the emissions inventory.

3.1.3. Analysis of idle data

Percent time at idle is another important factor in computing the HDDV contribution to the emissions inventory. The idle time for 244 vehicles is presented in Table 4. Percent idle time varied considerably between model years, with the newer vehicles showing less time at idle. The fleet-average percent time at idle was 29.4%, which is consistent with previous studies conducted by CARB (2003).

3.2. Application of activity data to estimate the emissions inventory

ECM download data were used to estimate NO_x emissions inventories and compared against EMFAC2002. In contrast to the EMFAC methodology of multiplying speed-corrected composite emission factors by VMT by speed bin, the ECM activity data were used to determine the weighting of emission factors assigned to the various modes of operation. Using this alternative methodology, NO_x emissions inventories were calculated for MHDDTs and HHDDTs.

Base emission factors for MHDDTs were gleaned from literature for vehicles operated over CARB's medium-duty diesel cycle (Gautam et al., 2003). This cycle consists of three modes of operation: low-speed transient, high-speed transient, and cruise. Base emission factors for 11 HHDDTs were obtained from emissions tests over the four-phase CARB HHDDT cycle, conducted by Bourns College of Engineering, Center for Environmental Research and Technology (CE-CERT), UCR, using their on-road Mobile Emissions Laboratory (Cocker et al., 2004). The four-phase CARB HHDDT cycle consists of a cold-start idle followed by three mobile phases: Creep, Transient, and Cruise. The use of the CARB four-phase cycle is in contrast to CARB's approach in EMFAC2002 of using the UDDS cycle. HHDDT emission factors were based on a fleet ranging from model year 1996 to 2000. Further details of the emission factors used for the HHDDTs can be found in Shah et al. (2006).

In comparing vehicle representation for emissions estimation, the data set Shah et al. (2006) presents the same number of vehicles as EMFAC2002, in the 1994–1997 and 1998 model year ranges. However, while EMFAC2002 uses assumptions of expected emission reductions for the 1999–2002 model year range, the data set Shah et al. (2006) use was based on two vehicles.

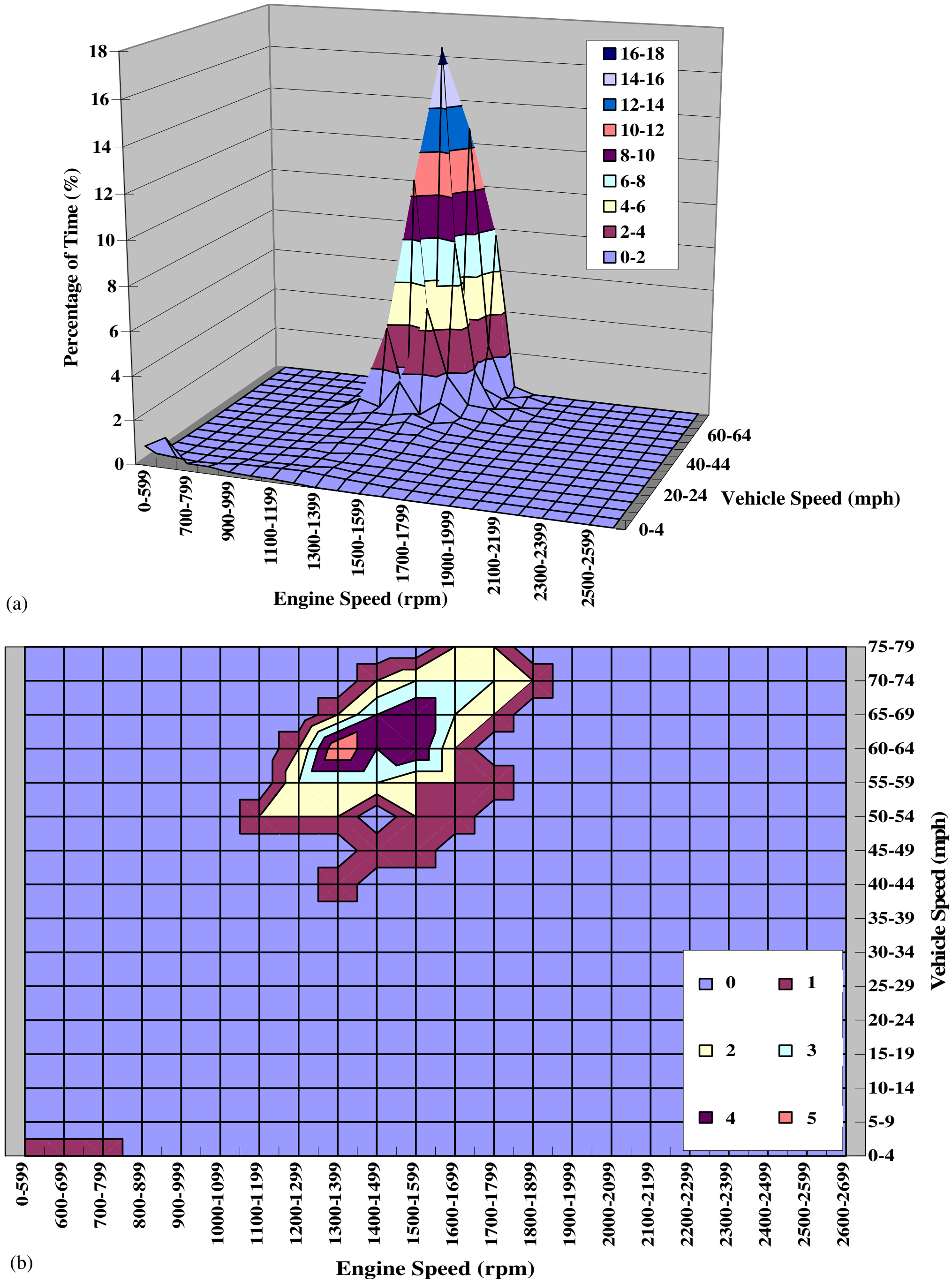

Fig. 2. Caterpillar 3406E single-peak "long-haul" use pattern. (a) Activity plot for one vehicle. (b) Histogram of 22 3406E single-peak vehicles.

Fleet-averaged base emission factors for the MHDDTs and HHDDTs can be seen in Table 6. For idling, hot-idle base emission factors were used rather than those from cold-start idle. To determine an emissions inventory for NO_x emissions, vehicle activity data were binned into categories identifying the operation as typical of one of the three modes of operation or idle. The percent of total operation time in each mode was used to determine the weighting. The mode-specific emission factors were combined based on this weighting and multiplied by the total population of the fleet. Weighting emission

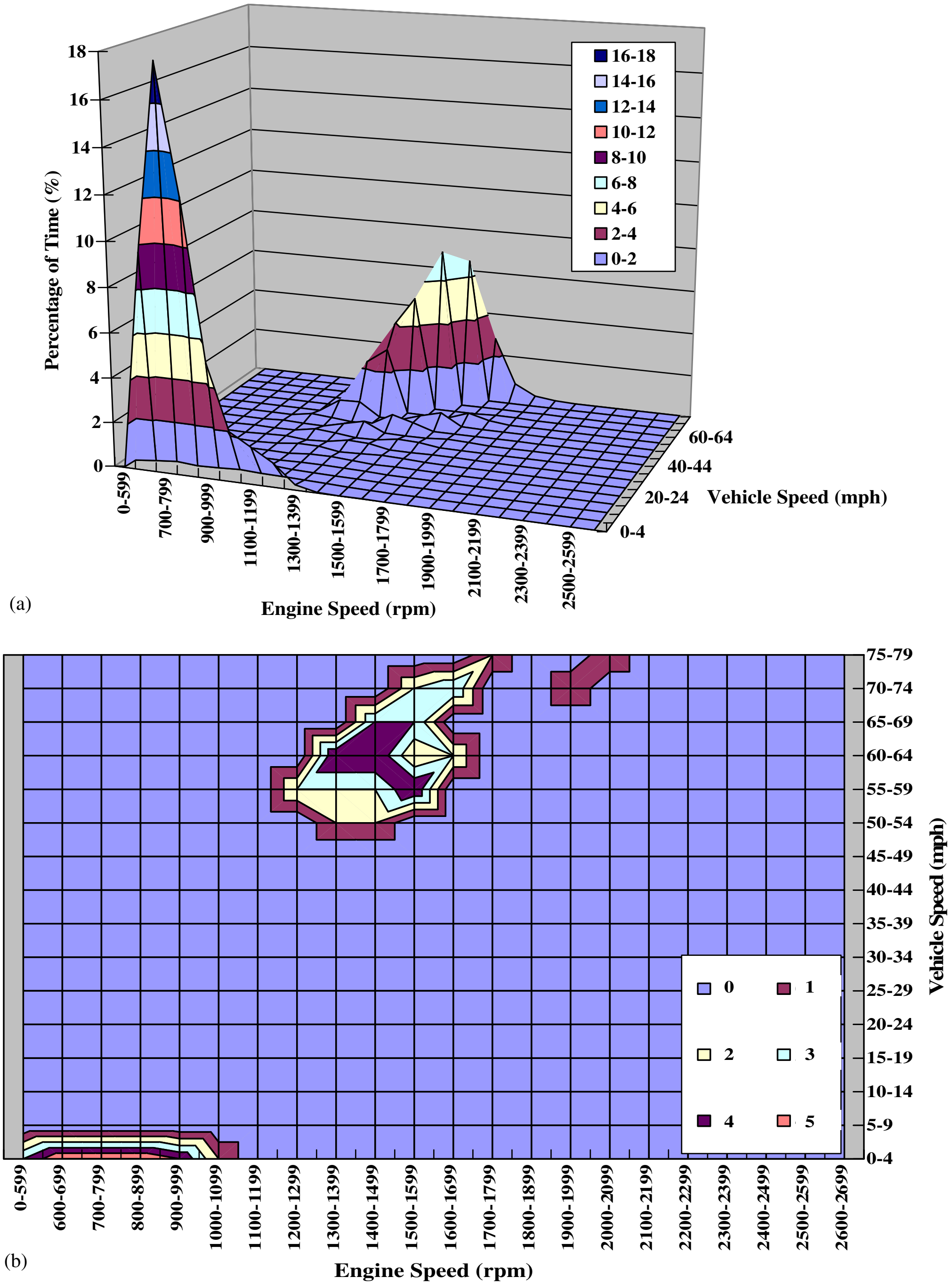

Fig. 3. Caterpillar 3406E two-peak ''medium-haul/intercity'' use pattern. (a) Activity plot for one vehicle; (b) Histogram of 8 3406E two-peak vehicles.

factors based on ECM activity data allows this modeling method to be adjusted as needed based on the region being modeled (i.e., more congested regions would have a higher weighting of the Creep phase).

The final emission values (ton day^{-1}) are presented in Table 6. The values for the MHDDTs are comparable to EMFAC2002 values. The value for HHDDTs is 26% greater than those reported in EMFAC2002. This difference is attributable to

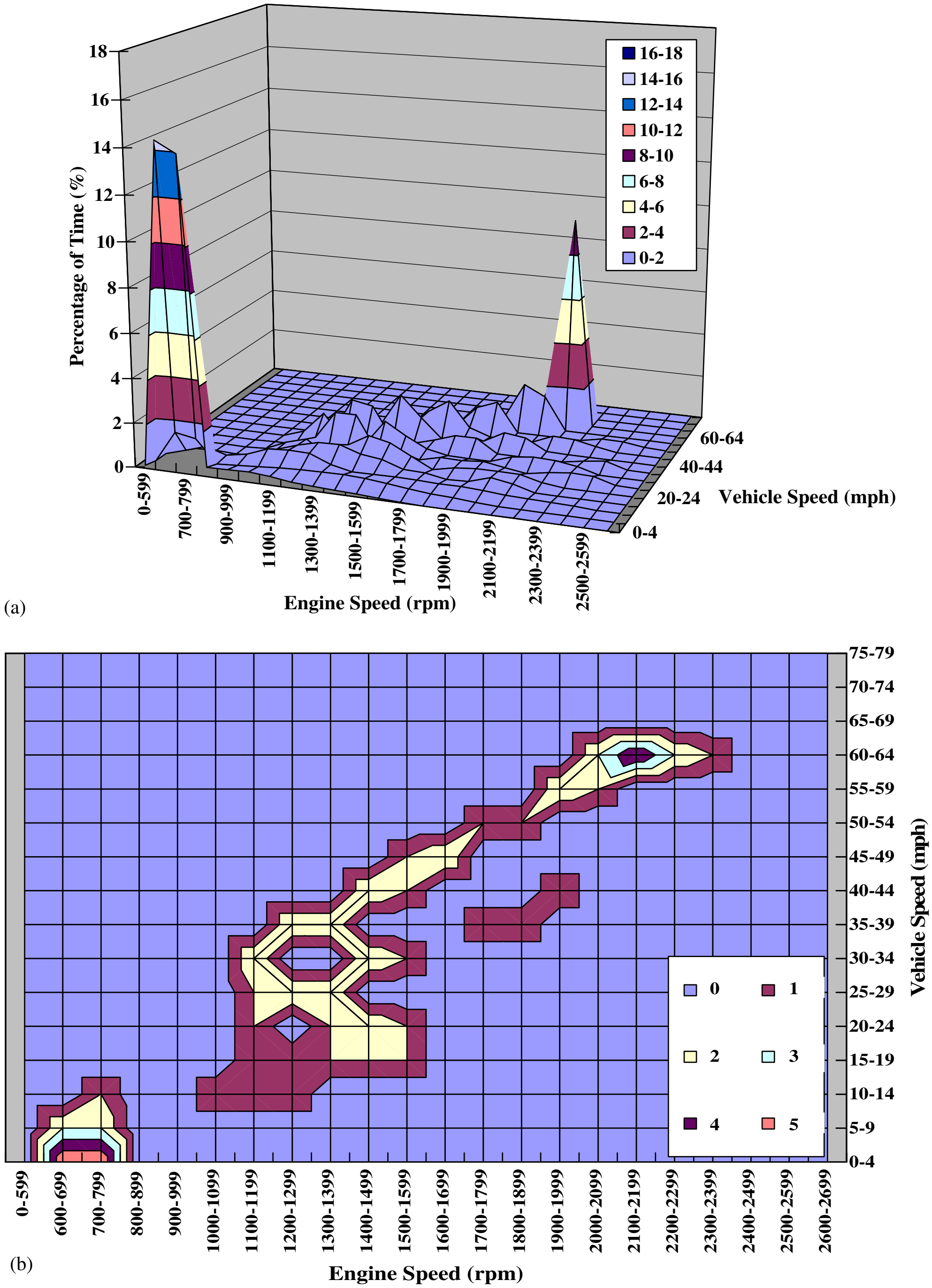

Fig. 4. Caterpillar 3126B mixed-peak "short-haul/incity" use pattern. (a) Activity plot for one vehicle; (b) Histogram of 10 3126B mixed-peak vehicles.

higher emission factors used in this study when compared to EMFAC2002 values, the difference in methodology used to calculate the emissions inventory, and the fact that EMFAC models emissions for vehicles ranging from 1965 to 2000, while the analysis in this paper uses emissions tests for vehicles from 1996 to 2000.

This estimation of the NO_x inventory attributable to these vehicles requires several key assumptions to be made: (1) downloads from the used-truck dealer

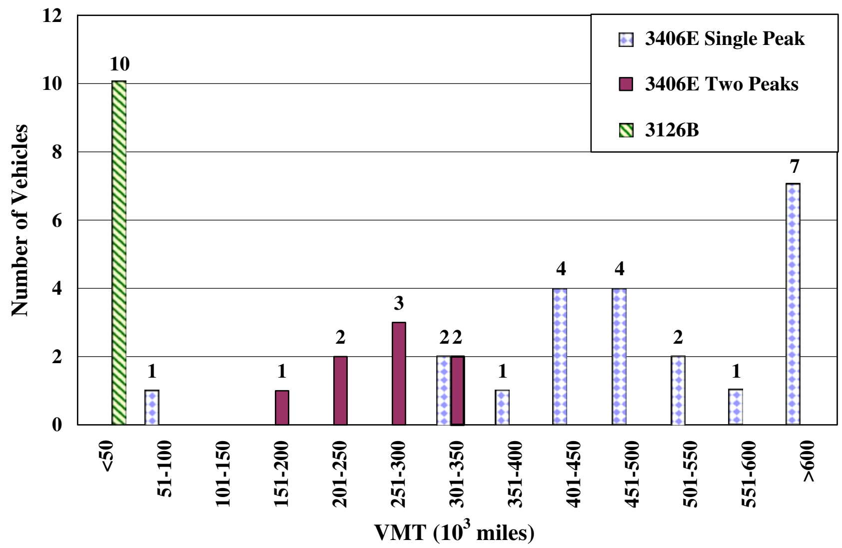

Fig. 5. Number of vehicles versus VMT for three speed/engine groupings.

Table 6
Summary of NO_x emission rates

Driving mode	Speed range[a] (mph)	NO_x emission factor (g min^{-1})	% Time of mode	NO_x emission rate (ton day^{-1})	
				This study	EMFAC2002
Medium-heavy-duty diesel trucks (MHDDTs)					
Idle	= 0	1.2	8.0		
Low-speed transient	0–15	2.72	43.7	140.85	142.42
High-speed transient	16–50	4.69	33.4		
Cruise	> 50	5.38	14.9		
Heavy-heavy-duty diesel trucks (HHDDTs)			*long-haul/medium-haul*		
Idle	= 0	1.2	39.5/39.5		
Creep	0–10	2.21	3.3/27.8	676.27	536.08
Transient	11–45	6.53	7.6/4.1		
Cruise	> 45	18.69	49.6/28.6		

[a]The dominated speed range of each driving mode was determined by the histogram of speed distribution in Figs. 2–4(b).

provide a fair representation of all the vehicles on the road, (2) fleet-average emission factors are representative of the fleet, and (3) ECMs have not been reset or tampered with. For the first assumption, it has been mentioned in previous sections that the ECM activity data agree with other reported values of vehicle activity and performance. For the second assumption, the data set used for determining the weighted emission factors consisted of only 11 vehicles, but did provide a range of engine model years from 1996 to 2000. Table 3 shows the range of model years of the vehicles from which ECM activity data were collected. Based on this distribution of vehicle model years and models, a larger database of vehicle emissions tests would improve the ability of the ECM activity method to estimate emissions inventories. However, its strengths are still evident with this small data set. The third assumption of non-tampering with engine ECM modules must at this point in time be taken on a good-faith basis. However, our analysis of the activity data did not indicate any tampering.

The similarity in values of both MHDDT and HHDDT NO_x inventories to those found in EMFAC2002 indicates that the ECM activity methodology can provide useful information for emissions inventories. Additionally, this method provides a complement to the traditional GPS and datalogger data collection methods. ECM downloads are easily obtained at repair shops and service stations, and can be quickly analyzed to determine HDDV activity parameters such as annual mileage accrual rates, and lifetime cumulative mileage estimates. This method is significantly cheaper than the traditional method ($\$50\,\text{record}^{-1}$ vs. $\sim\$2000\,\text{record}^{-1}$) and requires a relatively small amount of data to be collected: ECM downloads, vehicle information (age, class and type), and fleet-average emission factors. ECM data also covers vehicle operation over the entire life of the vehicle, whereas, traditional surveys cover only short periods of surveillance (days, weeks, or months).

Future evaluations of HDDV ECM data are planned and will be enhanced to include supplemental emissions testing of HDDV on a chassis dynamometer. Dynamometer testing will strive to quantify the emissions rate from several of the most common speeds and loads recorded in each truck's ECM record. The combination of activity data combined with individual vehicle emission rates will provide a strong quantitative grounding of the emission footprint of HDDVs over their useful life.

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The statements and opinions expressed in this paper are solely the authors' and do not represent the official position of the California Air Resources Board. The Air Resources Board is a department of the California Environmental Protection Agency. CARB's mission is to promote and protect public health, welfare, and ecological resources through effective reduction of air pollutants while recognizing and considering effects on the economy. The CARB oversees all air pollution control efforts in California to attain and maintain health-based air quality standards.

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