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Emissions Analysis of Heavy-Duty Truck Activity and Emissions Data

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Objectives

- University of California, Riverside (UCR), evaluated and summarize data collected from electronic control module (ECM) collected from 270 in-use heavy-duty diesel vehicles.
- ECM data varies by manufacturer, but generally includes engine identification and current engine configuration as well as the vehicle operating summaries.
- 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).
- Analysis of the data yielded various characteristics of the on-road fleet as well as an alternative means to estimate the contribution of these vehicles to the emissions inventory.

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California HDDV 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.

Project Descriptions

- 300 HDDVs' ECM downloads were collected as trucks were turned into a used-truck dealer.
- Three major heavy engine manufacturers: Caterpillar, Cummins and Detroit Diesel.
- Part of CARB's Measure 17 (M17) program.
- Vehicle ECMs for sale.

Variables Entered into Database

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		✓	

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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

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Vehicle Operating Characteristics

Summary Table

		Total Time	Total Distance	Total Fuel Used	Total Fuel Economy	Total Idle Fuel	Total Idle Time	% Time at Idle	Total PTO Fuel	Total PTO Time	% Time at PTO	Total Cruise Time	% Time at Cruise	Total Brake Time	Advertised Power
		hours	miles	gals	mpg	gals	hours	%	gals	hours	%	hours	%	hours	hp
Fleet Total	**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.

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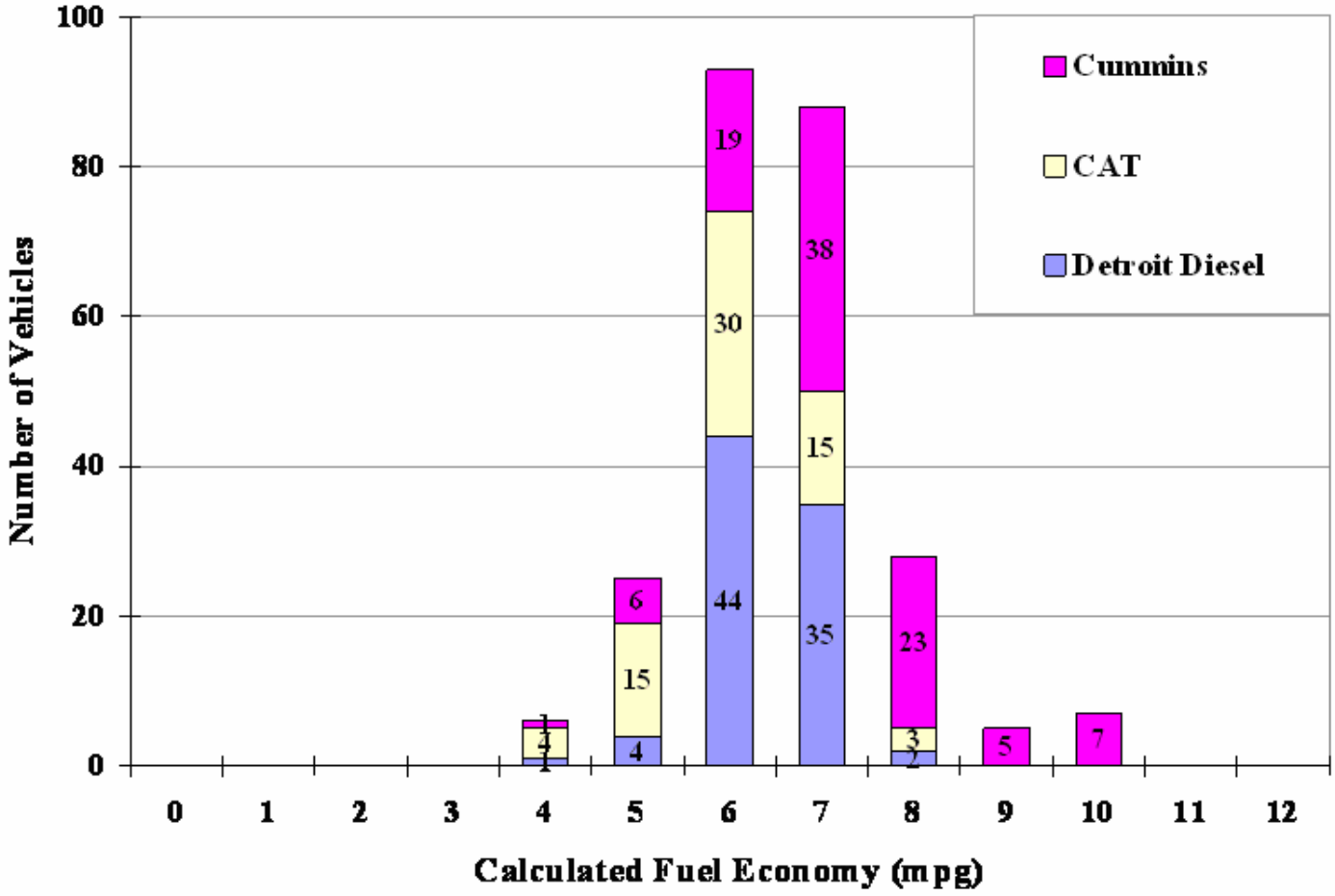
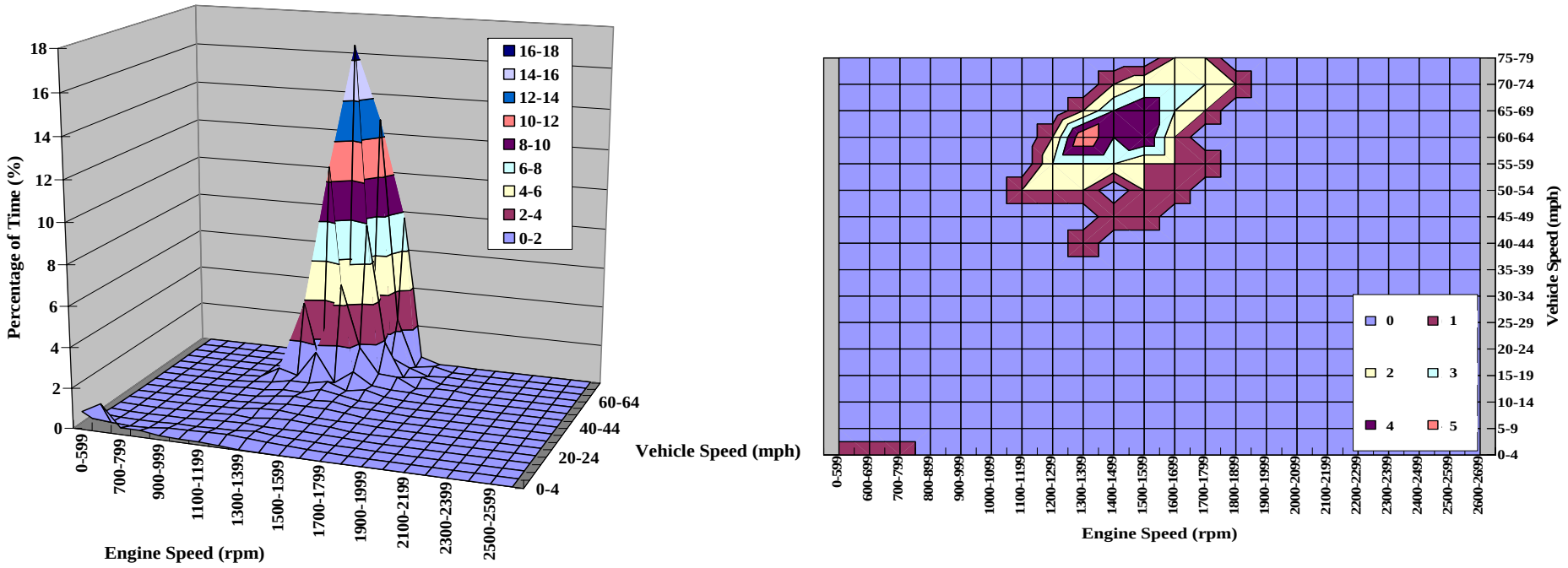
Vehicle Operating Characteristics

Fuel Economy



Analysis of Activity Data (I)



Caterpillar 3406E Single Peak "Long-haul" Use Pattern

(a) Activity Plot for One Vehicle;

(b) Histogram of 22 3406E Single Peak Vehicles

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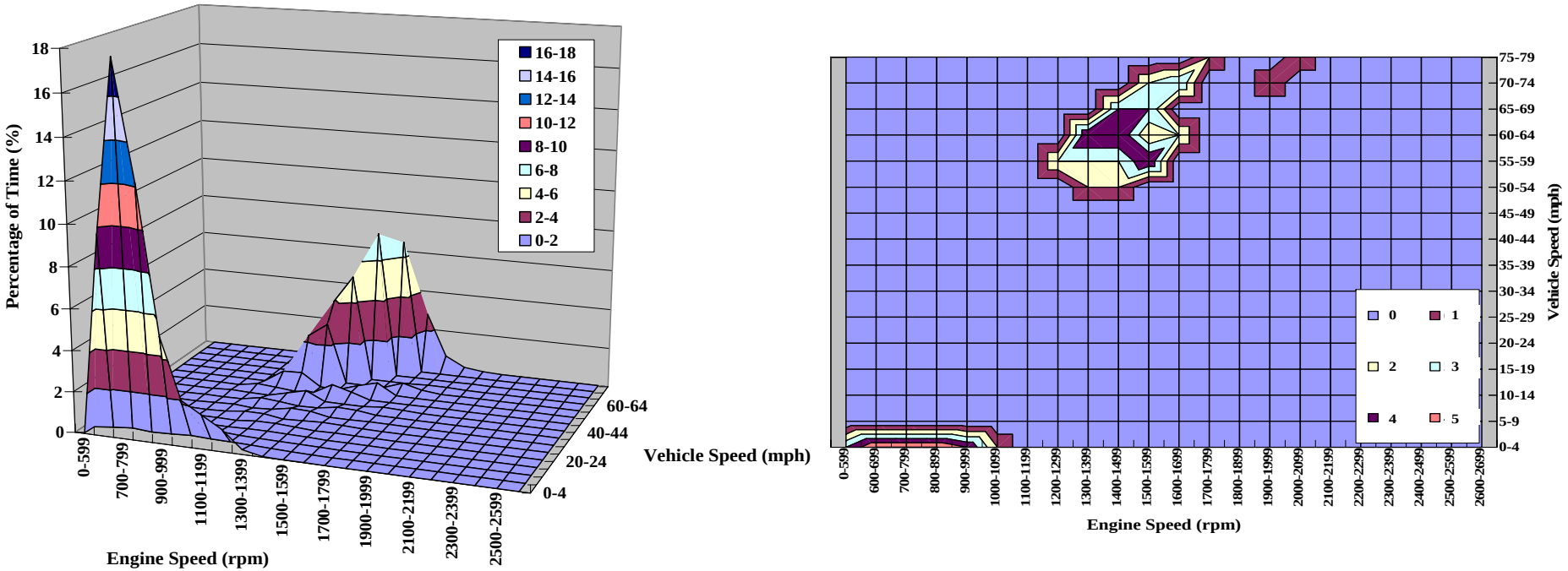
Analysis of Activity Data (II)



Caterpillar 3406E Two Peak "Medium-haul/Intercity" Use Pattern

(a) Activity Plot for One Vehicle.

(b) Histogram of 8 3406E Two Peak Vehicles.

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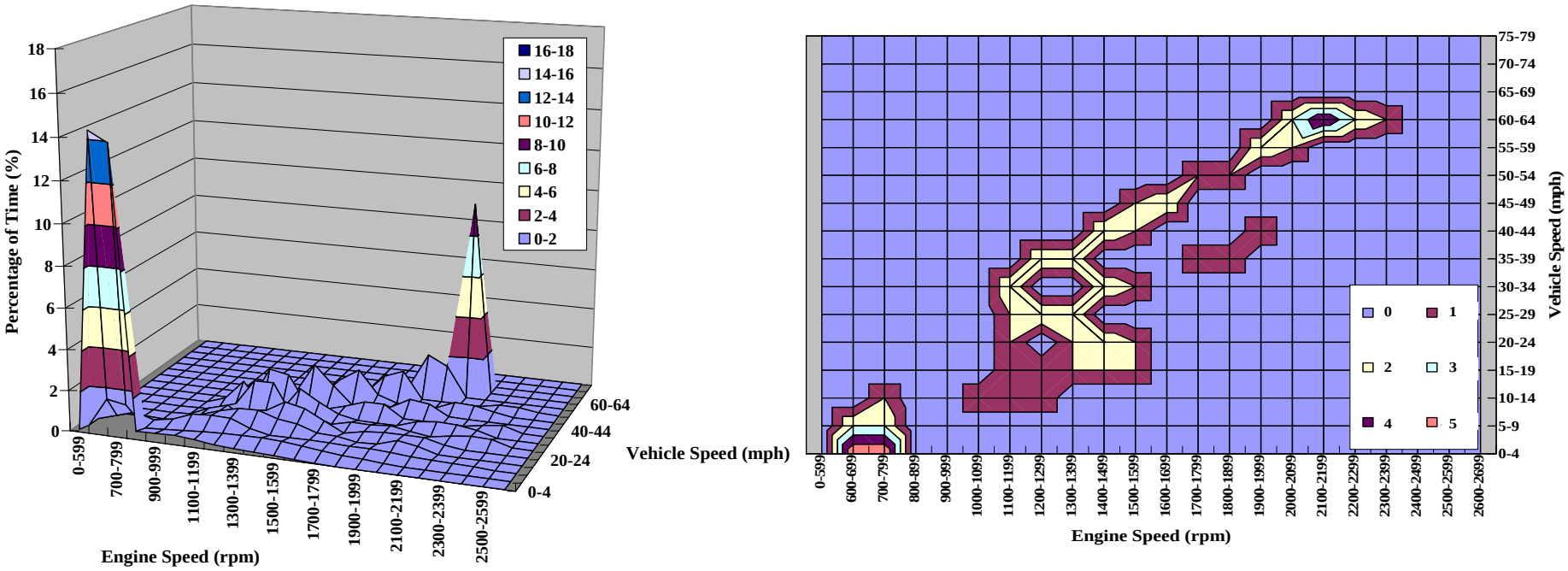
Analysis of Activity Data (III)



Caterpillar 3126B Mixed Peak "Short-haul/Incity" Use Pattern

(a) Activity Plot for One Vehicle.

(b) Histogram of 10 3126B Mixed Peak Vehicles.

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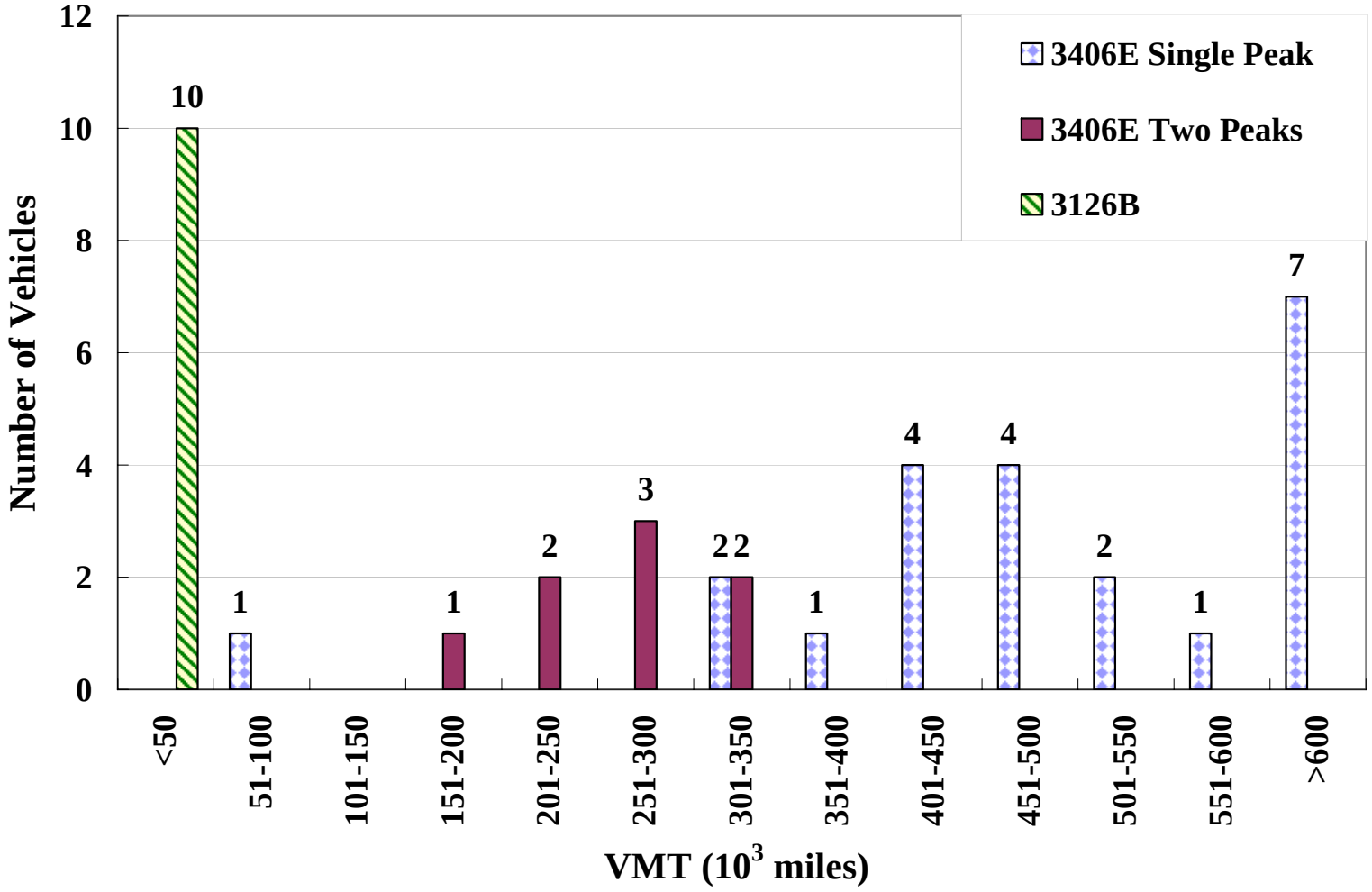
Analysis of Activity Data *(IV)*



Number of Vehicles versus VMT for Three Speed/Engine Groupings

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Tryouts on NOx Emissions Inventory

Driving Mode	Speed Range* (mph)	NO_x Emission Factor (g/min)	% Time of Mode	NO_x Emission Rate (tons/day)	
				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		

The dominated speed range of each driving mode was determined by the histogram of speed distribution in Figures *.(b).

Conclusions

- The similarity in values of both MHDDT and HHDDT NOx 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 data logger 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/record vs. ~$2,000/record) 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).

Conclusions

- 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 combine with individual vehicle emission rates will provide a strong quantitative grounding of the emission footprint of HDDVs over their useful life.