HEAVY-DUTY TRUCK POPULATION, ACTIVITY AND USAGE PATTERNS

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Prepared for:

California Air Resources Board
Research Division
2020 L Street
Sacramento, CA 95814

Prepared by:

Michael Fischer

Jack Faucett Associates
Western Regional Office
2855 Mitchell Drive, Suite 103
Walnut Creek, CA 94598

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its research and activities, please visit our Web site:

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ABSTRACT

Heavy-duty trucks (HDTs), both gasoline- and diesel-powered, are estimated to be among the largest contributors to the State of California's oxides of nitrogen (NOx) and particulate emissions inventory. The state implementation plan (SIP) for ozone contains a number of measures designed to control emissions from HDTs. However, HDTs are also one of the most poorly characterized categories of the emissions inventory. The objective of this study was to update historic (1960 to present) population distributions, develop a methodology for forcasting HDT populations (by weight class, fuel type, and age); characterize HDT activity levels (mileage accrual rates, VMT, and cumulative mileage); and gather new data on important activity parameters (speed profiles, number of trips per day, average speeds, and activity by time of day). Population and activity data were developed primarily by using Department of Motor Vehicles (DMV) registration data and historic data from the Truck Inventory and Use Survey (TIUS) conducted by the U.S. Bureau of the Census. It was estimated that in 1995 there were 661,287 HDTs registered in the state (59% gasoline and 41% diesel) that accounted for over 9.3 billion vehicle miles per year of driving. Out-of-state vehicles accounted for another 3.03 billion vehicle miles per year, or 24.6% of total statewide HDT VMT. While these data represent a major improvement over the data included in the current emissions models, a major conclusion of this study is that all users of HDT data in the state should work together to improve the available DMV data for analysis of historic HDT populations. Substantial new information about HDT activity was developed by instrumenting a small fleet (42 HDTs total) with onboard dataloggers. The analysis of the data indicated that the "average" HDT in the sample made 16.8 trips per day and 17.9 starts per day (starts include trips plus key-on to key-off events with trip length equal to zero mile) and that average speed was 30.6 mph. On average, trucks in the sample fleet spent 28.4% of their driving time at idle. The data also show some significant variations in activity based on weight class and usage (i.e., local vs. long haul driving). The activity data collected will be used to improve the ARB's emissions models, while some of the datalogger data from this study will be used to develop driving cycles in terms of speed versus time for HDT emission testing.

EXECUTIVE SUMMARY

BACKGROUND

Heavy-duty trucks (HDT) are increasingly becoming a focus of efforts to reduce mobile source emissions in California. This is because HDTs are a significant source of oxides of nitrogen (NO_x) and particulate matter (PM) emissions and HDT vehicle miles traveled (VMT) continue to grow more rapidly than VMT for light-duty vehicles. The State Implementation Plan (SIP) for ozone attainment includes a number of measures aimed at reducing emissions from HDTs and other proposals are being considered. Yet these regulations are being debated in a climate of considerable uncertainty regarding HDT emissions.

Much of this uncertainty stems from limitations in current emission modeling tools and their supporting data bases, which have not been revised for long time. For example, in the California Air Resources Board's (ARB) emission inventory model, MVEI7G, HDT weight specific population distribution is based on sales fractions provided in United States Environmental Protection Agency's (U.S. EPA) MOBILE4 model. In addition, speed distributions in the model are based on light-duty vehicles. There have also been very few attempts to develop emission test cycles for HDTs based on operating data from in-use vehicles. Activity data such as cumulative miles and accrual rates were obtained from 1987 Truck Inventory and Usage Survey.

OBJECTIVES

In July of 1994, the ARB began a research project to develop improved HDT population and usage data. The objectives of the project were to :

- Develop current and historic (1960 to present) estimates of HDT populations in California characterized by weight, fuel type, and vehicle age, using the most up-to-date data available. Both California and out-of-state registered vehicles operating in California were to be included.

- Develop age specific activity data including average mileage accrual rates, VMT, and cumulative mileage estimates for various classifications of HDTs. Data on HDT usage patterns such as long haul, short haul travel were also to be compiled and analyzed.

- Equip a sample fleet of HDTs with on-board data loggers in order to collect in-use data on important activity parameters such as speed profiles, number of daily trips, average trip speeds, average trip lengths, and activity by time of day. These data were to be collected over an 8 day period, while second-by-second traces of critical vehicle speed and load parameters were to be collected over a 24-hour period in order to aid the development of new, chassis dynamometer emission test cycles. Eight-day data were obtained on 31 trucks and 24-hour data on 11 trucks.

PROJECT RESULTS

Population Data
It was found that based on Department of Motor Vehicles (DMV) registration data, there were 661,287 HDTs registered in California in 1995. Of these 59% were gasoline and 41% were diesel trucks. In comparison, the ARB's latest version of motor vehicle emissions inventory model, MVEI7G1.0C, HDTs are 43% gasoline and 57% diesel. Exhibit ES-1 shows the weight and fuel specific HDT population as obtained from 1995 DMV data and as modeled in MVEI7G1.0C.

Exhibit ES-2 and ES-3 respectively show the distribution of gasoline and diesel HDTs based on DMV data. Exhibit ES-4 and ES-5 show the same distribution based on MVEI7G. The data in this study show that the fleet of diesel vehicles has a similar age distribution to that currently assumed in EMFAC but the fleet of gasoline vehicles includes a much higher percentage of older vehicles than the current model assumes. For example, the current version of the model assumes that in 1995, 34% of gasoline trucks were 4 years old or newer whereas this study's data show less than 10% of the gasoline trucks as 4 years old or newer. Exhibits ES-6 and ES-7 show results of population distribution for out-of-state trucks operating in California for the year 1991.

Activity
Based on analyses of the 1992 Truck Inventory and Usage Survey (TIUS) data, the 1992 statewide VMT for HDTs is estimated to be 12.3 billion miles. It is estimated that California registered HDTs account for 9.283 billion miles of this VMT within California. Diesel trucks account for 70.5% of the total VMT. Heavy-heavy trucks account for the largest share of VMT from California registered HDTs followed closely by light-heavy trucks (37% and 35% respectively). Average annual mileage accrual rates are higher for diesel trucks than for gasoline trucks (26,771 miles and 10,039 respectively) with heavy-heavy diesel trucks having the highest in-state average annual mileage accrual rates (41,685 miles). Diesel trucks also accrue an average of 7.91% of their annual miles outside of California (11.40% of heavy-heavy diesel annual mileage is accrued outside of the state). Exhibit ES-8 (a) and (b) shows a breakdown of annual statewide VMT and mileage accrual rates for California-registered HDTs. Out-of-state vehicles account for approximately 3.03 billion VMT in California, or approximately 24.60% of total HDT VMT. Virtually all of the out-of-state mileage is attributable to heavy-heavy diesels (91.1% of the total). Exhibit ES-9 shows annual VMT within California for out-of-state registered trucks.

Consistent with MVEI7G classification of HDTs, in this report HDTs are classified by gross vehicle weight (light, medium and heavy) and fuel type (gasoline and diesel) as follows:

	Gasoline	Diesel	Gross Vehicle Weight (lb)
Light-heavy duty	LHDG	LHDD	8,501 - 14,000
Medium-heavy duty	MHDG	MHDD	14,001 - 33,000
Heavy-heavy duty	HHDG	HHDD	> 33,000

In analyzing data collected from the instrumented trucks the heavy-heavy-duty truck class was further split into two classes as :

Heavy-heavy duty	HHDG	HHDD	33,001 - 80,000
Super-heavy-heavy-duty	SHHDG	SHHDD	> 80,000

Exhibit ES-1
HDT Population Comparisons Between 1995 DMV Data and MVEI7G1.0C

Weight Class	1995 DMV		MVEI7G1.0C	
LHDGV	281447	42.6%	301527	35.3%
MHDGV	105983	16.0%	69722	8.1%
HHDGV	3819	0.6%	0	0.0%
Total Gasoline HDTs	391249	59.2%	371249	43.4%
LHDDV	41036	6.2%	162363	19.0%
MHDDV	141922	21.4%	140079	16.4%
HHDDV	87080	13.2%	181219	21.2%
Total Diesel HDTs	270038	40.8%	483661	56.6%
Total HDTs	661287	100%	854910	100%

Exhibit ES-2
DMV - 1995 California HDV Registration Distribution by Vintage - Gasoline

Vintage	Total HDGs	% of Total	Total LHDG	% of Total	Total MHDG	% of Total	Total HHDG	% of Total
0	3,614	0.92%	2,510	0.89%	1,103	1.04%	1	0.03%
1	8,862	2.27%	6,876	2.44%	1,984	1.87%	2	0.05%
2	7,552	1.93%	5,787	2.06%	1,757	1.66%	8	0.21%
3	7,094	1.81%	5,221	1.86%	1,869	1.76%	4	0.10%
4	9,609	2.46%	6,733	2.39%	2,865	2.70%	11	0.29%
5	13,709	3.50%	9,743	3.46%	3,960	3.74%	6	0.16%
6	15,161	3.88%	11,277	4.01%	3,867	3.65%	17	0.45%
7	14,915	3.81%	11,196	3.98%	3,701	3.49%	18	0.47%
8	15,593	3.99%	11,941	4.24%	3,642	3.44%	10	0.26%
9	17,511	4.48%	13,984	4.97%	3,502	3.30%	25	0.65%
10	18,942	4.84%	14,708	5.23%	4,190	3.95%	44	1.15%
11	19,240	4.92%	15,817	5.62%	3,400	3.21%	23	0.60%
12	12,500	3.19%	10,535	3.74%	1,949	1.84%	16	0.42%
13	11,390	2.91%	9,206	3.27%	2,152	2.03%	32	0.84%
14	11,785	3.01%	8,803	3.13%	2,917	2.75%	65	1.70%
15	13,153	3.36%	9,319	3.31%	3,769	3.56%	65	1.70%
16	28,511	7.29%	22,319	7.93%	6,100	5.76%	92	2.41%
17	26,602	6.80%	21,571	7.66%	4,931	4.65%	100	2.62%
18	24,656	6.30%	20,183	7.17%	4,396	4.15%	77	2.02%
19	16,093	4.11%	12,381	4.40%	3,630	3.43%	82	2.15%
20	13,304	3.40%	8,273	2.94%	4,885	4.61%	146	3.82%
21	10,031	2.56%	5,227	1.86%	4,675	4.41%	129	3.38%
22	13,269	3.39%	7,465	2.65%	5,636	5.32%	168	4.40%
23	11,089	2.83%	6,328	2.25%	4,607	4.35%	154	4.03%
24	7,985	2.04%	4,446	1.58%	3,394	3.20%	145	3.80%
25	7,993	2.04%	4,229	1.50%	3,633	3.43%	131	3.43%
26	7,284	1.86%	3,866	1.37%	3,303	3.12%	115	3.01%
27	5,388	1.38%	2,897	1.03%	2,393	2.26%	98	2.57%
28	6,725	1.72%	4,834	1.72%	1,799	1.70%	92	2.41%
29	4,863	1.24%	3,772	1.34%	1,023	0.97%	68	1.78%
30	270	0.07%	0	0.00%	114	0.11%	156	4.08%
31	264	0.07%	0	0.00%	117	0.11%	147	3.85%
32	235	0.06%	0	0.00%	93	0.09%	142	3.72%
33	370	0.09%	0	0.00%	214	0.20%	156	4.08%
34+	5,687	1.45%	0	0.00%	4,413	4.16%	1,274	33.36%
Total	391,249	100.00%	281,447	100.00%	105,983	100.00%	3,819	100.00%

Exhibit ES-3
DMV - 1995 California HDV Registration Distribution by Vintage - Diesel

Vintage	Total HDDs	% of Total	Total LHDD	% of Total	Total MHDD	% of Total	Total HHDD	% of Total
0	11,038	4.09%	1,145	2.79%	6,875	4.84%	3,018	3.47%
1	12,690	4.70%	2,714	6.61%	6,846	4.82%	3,130	3.59%
2	12,968	4.80%	3,499	8.53%	6,696	4.72%	2,773	3.18%
3	12,487	4.62%	3,037	7.40%	6,846	4.82%	2,604	2.99%
4	15,168	5.62%	3,230	7.87%	8,264	5.82%	3,674	4.22%
5	21,957	8.13%	4,532	11.04%	11,550	8.14%	5,875	6.75%
6	20,207	7.48%	4,010	9.77%	9,196	6.48%	7,001	8.04%
7	17,657	6.54%	3,200	7.80%	8,521	6.00%	5,936	6.82%
8	17,425	6.45%	3,184	7.76%	8,291	5.84%	5,950	6.83%
9	17,021	6.30%	4,551	11.09%	6,633	4.67%	5,837	6.70%
10	16,353	6.06%	2,781	6.78%	6,870	4.84%	6,702	7.70%
11	15,028	5.57%	2,261	5.51%	6,380	4.50%	6,387	7.33%
12	7,806	2.89%	1,812	4.42%	2,916	2.05%	3,078	3.53%
13	7,341	2.72%	927	2.26%	3,103	2.19%	3,311	3.80%
14	8,376	3.10%	91	0.22%	4,239	2.99%	4,046	4.65%
15	7,940	2.94%	7	0.02%	5,507	3.88%	2,426	2.79%
16	9,379	3.47%	5	0.01%	6,113	4.31%	3,261	3.74%
17	6,613	2.45%	7	0.02%	4,334	3.05%	2,272	2.61%
18	5,021	1.86%	8	0.02%	3,129	2.20%	1,884	2.16%
19	3,067	1.14%	4	0.01%	2,025	1.43%	1,038	1.19%
20	3,501	1.30%	4	0.01%	2,191	1.54%	1,306	1.50%
21	3,907	1.45%	10	0.02%	2,666	1.88%	1,231	1.41%
22	3,556	1.32%	4	0.01%	2,316	1.63%	1,236	1.42%
23	2,556	0.95%	1	0.00%	1,706	1.20%	849	0.97%
24	1,735	0.64%	1	0.00%	1,228	0.87%	506	0.58%
25	1,698	0.63%	1	0.00%	1,254	0.88%	443	0.51%
26	1,465	0.54%	1	0.00%	1,147	0.81%	317	0.36%
27	820	0.30%	5	0.01%	675	0.48%	140	0.16%
28	550	0.20%	6	0.01%	397	0.28%	147	0.17%
29	340	0.13%	0	0.00%	261	0.18%	79	0.09%
30	268	0.10%	0	0.00%	221	0.16%	47	0.05%
31	223	0.08%	0	0.00%	176	0.12%	47	0.05%
32	135	0.05%	0	0.00%	115	0.08%	20	0.02%
33	137	0.05%	0	0.00%	116	0.08%	21	0.02%
34+	3,607	1.34%	0	0.00%	3,119	2.20%	488	0.56%
Total	270,038	100.00%	41,036	100.00%	141,922	100.00%	87,080	100.00%

Exhibit ES-4
MVEI7G - 1995 California HDV Registration Distribution by Vintage - Gasoline

Vintage	Total HDGs	% of Total	Total LHDG	% of Total	Total MHDG	% of Total
0	10833	2.92%	9648	3.20%	1185	1.70%
1	33433	9.00%	29725	9.86%	3708	5.32%
2	30186	8.13%	26588	8.82%	3598	5.16%
3	27739	7.47%	24627	8.17%	3113	4.46%
4	25829	6.96%	22877	7.59%	2952	4.23%
5	24264	6.54%	21527	7.14%	2737	3.92%
6	22620	6.09%	20014	6.64%	2606	3.74%
7	20978	5.65%	18511	6.14%	2467	3.54%
8	19335	5.21%	17072	5.66%	2263	3.24%
9	17693	4.77%	15702	5.21%	1991	2.86%
10	16048	4.32%	14466	4.80%	1582	2.27%
11	14406	3.88%	12611	4.18%	1794	2.57%
12	12762	3.44%	11537	3.83%	1225	1.76%
13	11387	3.07%	9953	3.30%	1434	2.06%
14	10623	2.86%	8577	2.84%	2046	2.93%
15	9858	2.66%	7899	2.62%	1959	2.81%
16	9094	2.45%	6018	2.00%	3076	4.41%
17	8329	2.24%	5154	1.71%	3176	4.55%
18	7566	2.04%	4666	1.55%	2901	4.16%
19	6382	1.72%	3104	1.03%	3278	4.70%
20	6382	1.72%	2998	0.99%	3383	4.85%
21	6381	1.72%	2175	0.72%	4206	6.03%
22	6382	1.72%	2155	0.71%	4228	6.06%
23	6381	1.72%	1965	0.65%	4416	6.33%
24	6382	1.72%	1978	0.66%	4405	6.32%
25	0	0.00%	0	0.00%	0	0.00%
26	0	0.00%	0	0.00%	0	0.00%
27	0	0.00%	0	0.00%	0	0.00%
28	0	0.00%	0	0.00%	0	0.00%
29	0	0.00%	0	0.00%	0	0.00%
30	0	0.00%	0	0.00%	0	0.00%
31	0	0.00%	0	0.00%	0	0.00%
32	0	0.00%	0	0.00%	0	0.00%
33	0	0.00%	0	0.00%	0	0.00%
34+	0	0.00%	0	0.00%	0	0.00%
Total	371274	100%	301546	100%	69728	100%

Exhibit ES-5
MVEI7G - 1995 California HDV Registration Distribution by Vintage - Diesel

Vintage	Total HDDs	% of Total	Total LHDD	% of Total	Total MHDD	% of Total	Total HHDD	% of Total
0	12505	2.59%	5563	3.43%	3868	2.76%	3075	2.76%
1	41689	8.62%	18652	11.49%	12852	9.17%	10185	9.17%
2	37219	7.69%	16895	10.40%	11107	7.93%	9217	7.93%
3	34237	7.08%	15449	9.51%	10376	7.41%	8412	7.41%
4	32900	6.80%	14637	9.01%	9936	7.09%	8327	7.09%
5	32254	6.67%	14148	8.71%	9785	6.98%	8322	6.98%
6	31753	6.56%	13535	8.34%	9531	6.80%	8688	6.80%
7	30019	6.21%	12414	7.65%	8912	6.36%	8693	6.36%
8	27294	5.64%	10877	6.70%	8106	5.79%	8311	5.79%
9	24557	5.08%	9549	5.88%	7504	5.36%	7504	5.36%
10	21828	4.51%	8592	5.29%	6109	4.36%	7127	4.36%
11	19108	3.95%	5900	3.63%	5292	3.78%	7916	3.78%
12	16379	3.39%	6352	3.91%	4589	3.28%	5438	3.28%
13	14638	3.03%	4718	2.91%	4104	2.93%	5815	2.93%
14	13700	2.83%	2647	1.63%	3947	2.82%	7106	2.82%
15	12849	2.66%	1825	1.12%	4020	2.87%	7004	2.87%
16	12003	2.48%	609	0.37%	3254	2.32%	8140	2.32%
17	11166	2.31%	0	0.00%	3058	2.18%	8108	2.18%
18	10323	2.13%	18	0.01%	2737	1.95%	7568	1.95%
19	9481	1.96%	0	0.00%	2506	1.79%	6975	1.79%
20	8637	1.79%	0	0.00%	2381	1.70%	6256	1.70%
21	7792	1.61%	0	0.00%	1678	1.20%	6114	1.20%
22	7196	1.49%	0	0.00%	1419	1.01%	5777	1.01%
23	7094	1.47%	0	0.00%	1397	1.00%	5698	1.00%
24	7095	1.47%	0	0.00%	1628	1.16%	5467	1.16%
25	0	0.00%	0	0.00%	0	0.00%	0	0.00%
26	0	0.00%	0	0.00%	0	0.00%	0	0.00%
27	0	0.00%	0	0.00%	0	0.00%	0	0.00%
28	0	0.00%	0	0.00%	0	0.00%	0	0.00%
29	0	0.00%	0	0.00%	0	0.00%	0	0.00%
30	0	0.00%	0	0.00%	0	0.00%	0	0.00%
31	0	0.00%	0	0.00%	0	0.00%	0	0.00%
32	0	0.00%	0	0.00%	0	0.00%	0	0.00%
33	0	0.00%	0	0.00%	0	0.00%	0	0.00%
34+	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Total	483718	100%	162379	100%	140096	100%	181243	100%

Exhibit ES-6
1991 Out-of-State HDV Population by Vintage - Gasoline

Vintage	Total On-Road HDGVs	% of Total	Total On-Road LHDGV	% of Total	Total On-Road MHDGV	% of Total	Total On-Road HHDGV	% of Total
0	308	2.48	49	0.96	71	1.71	188	5.97
1	444	3.58	61	1.19	120	2.89	263	8.35
2	1,437	11.58	128	2.51	1,022	24.60	287	9.10
3	1,043	8.41	192	3.77	495	11.92	356	11.27
4	349	2.81	107	2.09	109	2.63	133	4.22
5	507	4.09	87	1.70	245	5.90	175	5.55
6	587	4.73	75	1.47	236	5.68	277	8.76
7	399	3.22	65	1.27	191	4.60	144	4.55
8	227	1.83	33	0.65	82	1.97	112	3.55
9	231	1.86	22	0.44	80	1.93	128	4.05
10	263	2.12	24	0.46	94	2.25	146	4.63
11	257	2.07	40	0.77	126	3.04	91	2.88
12	2,272	18.31	1,819	35.68	275	6.63	178	5.63
13	1,324	10.67	1,073	21.05	145	3.49	105	3.34
14	1,042	8.40	834	16.35	132	3.17	76	2.42
15	535	4.31	394	7.72	79	1.90	62	1.96
16	190	1.53	11	0.21	104	2.50	75	2.38
17	191	1.54	25	0.49	99	2.38	67	2.13
18	200	1.61	26	0.52	111	2.66	63	2.00
19	134	1.08	11	0.21	74	1.78	50	1.59
20	101	0.82	5	0.10	57	1.36	40	1.25
21	65	0.52	4	0.08	33	0.79	28	0.88
22	65	0.52	4	0.08	36	0.86	25	0.79
23	49	0.39	5	0.10	32	0.76	12	0.38
24	38	0.31	1	0.02	21	0.51	16	0.50
25	26	0.21	1	0.02	16	0.38	9	0.29
26	19	0.15	1	0.02	9	0.22	9	0.29
27	26	0.21	1	0.02	20	0.48	5	0.17
28	13	0.10	1	0.02	8	0.19	4	0.13
29	13	0.10	0	0.00	5	0.13	8	0.25
30	2	0.02	0	0.00	1	0.03	1	0.03
31	4	0.03	0	0.00	3	0.06	1	0.03
32	5	0.04	0	0.00	5	0.13	1	0.03
33	7	0.06	0	0.00	3	0.06	4	0.13
34+	34	0.29	0	0.00	17	0.41	17	0.54
Total	12,409	100.0	5,099 41.09	100.0	4,154 33.48	100.00	3,156 25,43	100.00

Exhibit ES-7
1991 Out-of-State HDV Population by Vintage - Diesel

Vintage	Total On-Road HDDVs	% of Total	Total On-Road LHDDV	% of Total	Total On-Road MHDDV	% of Total	Total On-Road HHDDV	% of Total
0	47,676	10.94	498	4.83	5,179	7.55	41,999	11.77
1	52,302	12.00	1,329	12.90	8,905	12.98	42,068	11.79
2	66,517	15.26	1,217	11.82	9,443	13.76	55,857	15.65
3	49,987	11.47	1,000	9.71	7,575	11.04	41,412	11.60
4	42,583	9.77	805	7.81	7,163	10.44	34,615	9.70
5	34,148	7.83	958	9.30	7,666	11.17	25,524	7.15
6	35,010	8.03	876	8.50	6,276	9.15	27,858	7.80
7	26,638	6.11	1,027	9.98	4,168	6.07	21,444	6.01
8	10,353	2.38	510	4.95	1,578	2.30	8,265	2.32
9	9,924	2.28	190	1.84	1,604	2.34	8,130	2.28
10	10,354	2.38	166	1.61	1,311	1.91	8,878	2.49
11	9,933	2.28	186	1.80	1,749	2.55	7,998	2.24
12	11,662	2.68	324	3.15	1,748	2.55	9,590	2.69
13	8,026	1.84	290	2.81	1,367	1.99	6,369	1.78
14	5,720	1.31	190	1.84	739	1.08	4,792	1.34
15	2,622	0.60	96	0.93	350	0.51	2,176	0.61
16	2,227	0.51	57	0.55	225	0.33	1,945	0.55
17	2,738	0.63	104	1.01	414	0.60	2,221	0.62
18	2,453	0.56	132	1.28	431	0.63	1,890	0.53
19	1,549	0.36	148	1.43	203	0.30	1,199	0.34
20	842	0.19	53	0.51	105	0.15	684	0.19
21	649	0.15	36	0.35	119	0.17	495	0.14
22	519	0.12	30	0.29	83	0.12	406	0.11
23	373	0.09	26	0.26	99	0.14	248	0.07
24	219	0.05	16	0.15	24	0.03	179	0.05
25	191	0.04	11	0.10	30	0.04	150	0.04
26	126	0.03	11	0.10	7	0.01	109	0.03
27	80	0.02	4	0.04	4	0.01	72	0.02
28	61	0.01	3	0.03	8	0.01	50	0.01
29	49	0.01	1	0.01	7	0.01	41	0.01
30	51	0.01	3	0.03	9	0.01	40	0.01
31	34	0.01	1	0.01	1	0.00	32	0.01
32	26	0.01	1	0.01	3	0.00	22	0.01
33	31	0.01	1	0.01	1	0.00	29	0.01
34+	179	0.04	5	0.05	13	0.02	161	0.05
Total	435,850	100.00	10,299 2.36	100.00	68,605 15.74	100.00	356,946 81.90	100.00

Exhibit ES-8a
California - Annual In-State VMT by Vehicle Class (In Millions of Miles)

Vehicle Class	CALIFORNIA[1]		NATIONAL	
	GAS	DIESEL	GAS	DIESEL
8,500 - 14,000	2,858	413	9,762	5,324
14,001 - 33,000	712	1,855	6,285	12,781
> 33,000	45	3,399	773	76,250
All HDVs	3,615	5,668	16,821	94,355

Exhibit ES-8b
Annual Average In-State Mileage Accrual Rate by Vehicle Class (in Miles)

Vehicle Class	CALIFORNIA		NATIONAL	
	GAS	DIESEL	GAS	DIESEL
8,500 - 14,000	11,591	17,259	10,261	19,191
14,001 - 33,000	6,563	17,465	6,603	19,389
> 33,000	8,983	41,685	6,604	50,733
All HDVs	10,039	26,771	8,325	38,677

Exhibit ES-9
Annual VMT for Out-Of-State Registered Trucks in Millions of Miles

Vehicle Class	GAS		DIESEL	
	VMT	%	VMT	%
8,500 - 14,000	11	51.53%	33	1.09%
14,001 - 33,000	5	23.77%	222	7.37%
> 33,000	5	24.70%	2,753	91.54%
All HDVs	21	100%	3,007	100%

[1] National and California annual mileage accumulation were calculated using different population data sources. (National estimates were derived using TIUS population data while California estimates utilize ARB population data in conjunction with TIUS activity data). The California values in Exhibits ES-6a and ES-6b refer only to in-state annual VMT and in-state accrual rate for California registered trucks..

Instrumented Vehicles
Thirty-one trucks representing the HDT fleet of California registered trucks with respect to weight class, fuel type, and area of operation (local, short haul, or long haul driving) were instrumented with dataloggers to obtain real time activity. Due to non-response and self-selection bias, the sample of 31 trucks represented in the data presented in this report tends to most greatly under-represent long haul trucks in the heaviest weight classes.

Exhibit ES-10 shows various activity estimates obtained from the data collected through instrumented trucks. Fig. ES-1 shows graphs of start distribution by weight class.

Exhibit ES-10
Activity Estimates from Instrument Data

Weight Class	Number of Trucks	Average Trip[1] Length (minutes)	Average Trip[1] Length (miles)	Average Speed (mph)
LHDGV	4	9.69	4.73	29.27
MHDGV	3	3.26	1.29	23.82
LHDDV	3	9.97	3.97	23.88
MHDDV	9	18.17	9.26	30.57
HHDDV	5	58.07	22.23	22.97
SHHDDV	7	16.88	10.55	37.51

Weight Class	Number of Trucks	Number of Starts[2] per Day	Number of Trips per Day	Average Idle Time[3] (min)	Average Soak Time[4] (min)
LHDGV	4	20.1	19.7	1.91	69.22
MHDGV	3	38.9	38.3	1.24	38.02
LHDDV	3	6.7	6.3	21.46	218.10
MHDDV	9	15.3	14.9	0.45	85.85
HHDDV	5	5.5	4.6	5.71	234.98
SHHDDV	7	12.9	10.4	0.85	61.91

1 Trips are defined as any time the vehicle traveled a distance greater than 0.001 miles.
2 Starts are distinguished from trips as any time the engine was turned on regardless of whether the truck was moved.
3 Average Idle Time is the average duration of an idle event (miles=0). It does not include idle time within a trip which has covered a distance greater than 0.001 miles
4 Average Soak Time (time-off) is the average duration a vehicle has been turned off before the next start.

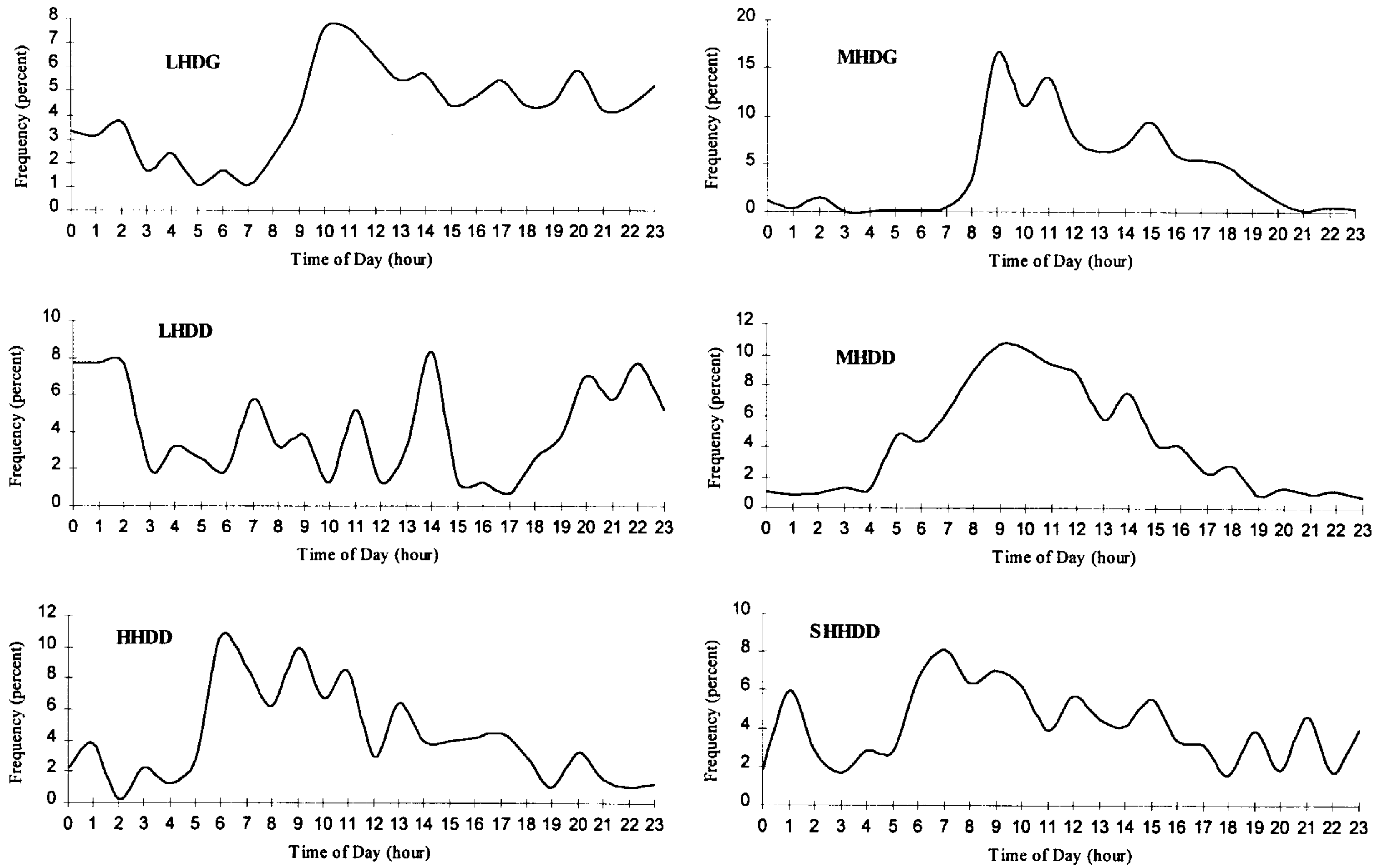


Fig. ES-1 Start Distribution by Weight Class

CONCLUSIONS

HDT population data has been updated using up-to-date DMV data and using Truck Inventory and Use Survey (TIUS) data base for the years 1977-1992. However, there are two areas of weakness that remain in the population data. One is populations prior to 1977 are not well characterized and the other is the use of 1995 ARB/DMV age distribution data for all calendar years. This study recommends that the ARB, the California Energy Commission, and Caltrans work together to develop consistent procedures for processing and archiving DMV registration files so that a detailed, historic database for HDT populations can be developed for future analyses.

Activity data by weight class and fuel type has also been significantly improved in this study through the use of the most current TIUS data (1992). Activity of out-of-state HDTs operating in California was also characterized in this study using, for the first time, data from the International Registration Plan (IRP) records. The approaches used to develop estimates of activity by out-of-state vehicles hold much promise for the future, but the data used in this study are beginning to become obsolete. New efforts are needed to study the impacts of out-of-state HDT activity through updated IRP data base and new roadside surveys.

The instrumentation of 31 HDTs for speed bin data and 11 HDTs for second-by-second data has made major contributions to understanding truck usage and driving patterns. The instrumentation was generally effective and represents a relatively inexpensive tool for gathering this type of data. The basic data sets that were compiled seem to address all the major activity parameters that are significant for emission modeling and test cycle development. Sampling presents the biggest challenge for getting statistically reliable data from this type of data collection error and there are potential sampling bias in the results of this study. The variety of truck usage clearly needs to be taken into account in designing future sampling plans and this will require large samples. However, the data collected in this study does show some variations in the speed profiles and trip-making patterns of trucks in different weight classes that suggest a need to develop alternative test cycles by weight class.

The activity data collected will be used to improve the ARB's emissions models, while some of the datalogger data from this study will be used to develop driving cycles in terms of speed versus time for HDT emission testing.

1 INTRODUCTION

As California attempts to solve air pollution problems that plague most of its major urban areas, attention is increasingly focused on heavy-duty trucks (HDT). This is due, to a large extent, to the success of programs to reduce emissions from light-duty vehicles, which comprise the largest fraction of emissions from on-road sources. Advances in light-duty vehicle emission control technologies have allowed for ever more stringent emission standards. However, these standards are pushing light-duty vehicle manufacturers toward the technological limitation of emission control. In the meantime, HDT vehicle miles traveled (VMT) continue to grow more rapidly than light-duty VMT and HDT's are becoming an increasingly significant contributor to mobile source emissions. The ARB is responsible for statewide mobile source emission regulation and the establishment of vehicle emission standards for HDTs. A number of major regulatory proposals are being considered for HDT's including a recent agreement reached between the ARB and the United States Environmental Agency (U.S. EPA) to lower emission standards for NOx from HDT's to 2.0 grams/brake-horsepower-hour (g/bhp-hr) in the year 2004. Other proposals are being investigated for the State Implementation Plan (SIP). Yet these regulations are being debated in a climate of considerable uncertainty regarding HDT emissions.

Much of this uncertainty stems from limitations in current emission modeling tools and their supporting data bases. Historically, the ARB's motor vehicle emissions model, EMFAC, included a single composite emission factor for each fuel type (diesel and gasoline) that was developed by combining weight specific emission rates weighted by sales fractions. This approach combined emission rates for HDTs into model year composite emission rates by fuel type.

Beginning with version MVEI7G, emissions are represented by two fuel types (gasoline and diesel) and three weight classes. The three weight classes are:

- Light-heavy (8500 lbs. - 14,000 lbs. Gross Vehicle Weight (GVW))
- Medium-heavy (14,001 lbs. - 33,000 lbs. GVW)
- Heavy-heavy (over 33,000 lbs. GVW).

Separating the HDT population into three vehicle classes and two fuel type categories within EMFAC has some significant long-term advantages:

- The model can now take into account the differences in population characteristics (e.g., age and fuel type distributions) by weight class reflecting the different usage characteristics of trucks of different weight classes.

- The model can now be used to calculate emissions based on different activity levels by weight class that reflect different usage characteristics of trucks of different weights.

- Separate speed distributions and speed correction factors can be developed for trucks of different weight classes reflecting different usage characteristics.

- Policy options that are targeted to different segments of the truck market can be evaluated for their emissions impacts more accurately. Likewise, changes in the general regulatory environment of trucking (such as changes in truck size and weight restrictions) and technology changes that affect different weight classes differently can now be accounted for in the model.

All of these capabilities introduced with EMFAC7G are expected to make truck emission inventories more accurate and to result in more informed environmental policy decisions.

In order to realize the full capabilities that EMFAC7G has brought to ARB's analysis of HDT emissions, a variety of new and updated truck population and activity data needed to be incorporated into the activity portion of the motor vehicle inventory model (BURDEN). The approaches that were used to incorporate these data in version EMFAC7G included the following:

- Registration distributions were required that were weight class and fuel type specific. Since no such data were immediately available for the California trucking fleet, the following approach was adopted to construct these distributions. Registration fractions (i.e., age distribution) for all diesel trucks and all gasoline trucks were taken from EMFAC7F. Sales fractions (by weight class and fuel type) for each model year (historic and forecasted) were taken from national data contained in U.S. EPA's MOBILE4 model and these were weighted against the HDT registration fractions to derive weight class specific registration distributions by calendar year.

- Activity data (annual VMT and cumulative mileage by weight class, fuel type and age) were developed using national data from the 1982 Truck Inventory and Use Survey (TIUS) conducted by the U.S. Bureau of Census.

- All VMT from out-of-state registered trucks was assumed to be contributed by heavy heavy-duty diesel trucks. The percent of total California truck VMT contributed by out-of-state vehicles was determined from the 1982 TIUS data.

- No adjustments were made to the speed distributions for HDT's. These were based on the same data used in EMFAC7F which assumes the same speed distribution for trucks as for light-duty vehicles.

- Emission rates for HDT's continue to be based on emission tests conducted with heavy-duty engine dynamometers, converted from g/bhp-hr to g/mile emission rates using conversion factors that are a function of fuel density, brake specific fuel consumption of the engine, and mile per gallon fuel efficiency characteristics of the vehicle.

These initial approaches to providing the new population and activity data needed in order to utilize the HDT analysis capabilities of EMFAC7G, were always intended by ARB staff to be a starting point. Staff believed that additional research could develop a more robust data base to support the new modeling capabilities and provide the ARB with the ability to more accurately model HDT emissions.

Thus, in July of 1994, the ARB began a research project to develop improved HDT population, activity and usage data. The objectives of the project were:

- Develop current and historic (1960 to present) estimates of HDT populations in California disaggregated by weight class, fuel type, and age. To the maximum extent possible, these population data were to improve on the data currently incorporated in EMFAC/BURDEN by using actual California populations and registration fractions. The data should be more current than what is now in EMFAC.

- Develop data on the population of out-of-state HDTs operating in California, also disaggregated by age, weight class, and fuel type.

- Develop a methodology for forecasting future HDT populations in California (disaggregated by age, weight class, and fuel type) which at least takes into account historic sales rates and attrition rates.

- Develop annual mileage accrual rates and cumulative odometer readings by fuel type, vehicle age, and weight class for use in emission inventory calculations. This should be determined for both in-state and out-of-state populations.

- Determine the percent of mileage driven out-of-state by vehicles based in California.

- Develop fuel economy factors by vehicle weight class, fuel type, and age.

- Determine how general activity of the HDT population varies as a function of other variables not currently included in the model, such as, area of operation (i.e., local, short haul, long haul), type of use (i.e., agricultural, mining, construction, etc.), and jurisdiction (i.e., public, private, fleet, independent, etc.).

- Develop weight and fuel specific (if different) speed (distributions) that are based on instrumentation of actual in-use trucks.

- Develop second-by-second traces of vehicle speed, engine speed, engine load, and road gradient from on-board instrumentation of in-use trucks that could be used to develop new chassis dynamometer emission test cycles. This would allow emission rates to be estimated directly on a g/mi basis.

The project was conducted in five tasks:

- Task 1 involved the development of HDT populations using existing published data sources. Data on historic in-state population and registration distributions were developed for calendar years 1960 to 1995. These data were disaggregated by weight class, fuel type, and age. Population data by weight class, fuel type and age for out-of-state vehicles operating in California were also developed.

- Task 2 involved the development of activity data from secondary data sources. Estimates were developed on annual mileage accrual rates, average odometer reading by age, and fuel economy.

- Task 3 involved the collection of data through instrumentation of in-use HDTs. Two data sets were collected. Thirty-one trucks were instrumented for speed bin data (speed profiles, number of starts/ trips, time of day of trips) over an eight day period. An additional 11 trucks were instrumented for second-by-second data (road speed, engine speed, and in most cases, intake manifold pressure, and road gradient) over a 24-hour period.

- Task 4 involved analysis of the data collected in Task 3. Analyses included development of speed histograms, number of starts by time of day all disaggregated by weight class and fuel type.

- Task 5 was the preparation of this final report.

This report is organized in five chapters. Following this introductory chapter, Chapter 2 provides a description of the literature searches conducted for the project and includes a brief overview of each data source and an assessment of the strengths and weaknesses of each data set with respect to the specific objectives of Tasks 1 and 2. At the conclusion of this chapter, a summary of the data sources that were selected for estimating the population and activity data bases and the reasons for each data source's selection is included. Appendix 1 provides a more detailed description of each of these data sets.

Chapter 3 describes the development of population data. This chapter describes the types of population data that were developed, reviews the data sources that were used, and describes the methodologies for estimating registration distributions and historic populations for vehicles registered in-state and the separate methodologies used to estimate registration distributions and populations for out-of-state trucks.

Chapter 4 describes the results of the activity data compilation efforts. Again, methodologies and data sources are discussed. The data includes information about mileage accrual rates and VMT by weight, fuel type, and vehicle age as well as characterizations of the population including usage breakdown, fuel economy, and other relevant variables.

The final chapter describes HDT usage data collected through on-board instrumentation of in-use trucks. This chapter describes the types of data collected, the instrumentation used, the methodology for procuring vehicles for the test program, and the actual data that were collected. Descriptive summary statistics for these vehicles are also included in the final chapter of the report.

2 LITERATURE REVIEW AND DATA SOURCES

In order to compile the population and activity data required to meet the objectives of Tasks 1 and 2 of the project, JFA conducted an exhaustive literature search. The following types of data were sought:

- Current and historic data on truck populations in California. These data needed to be able to be disaggregated by the ARB weight classes, fuel type (gasoline and diesel), and vehicle age to the maximum extent possible. Ideally, population data were needed for each calendar year back to 1960 and the age profile of vehicles (registration distribution) needed to extend back 35 years, i.e., for each calendar year the data needed to provide the number (or fraction) of vehicles that were 0 years old, 1 year old, 2 years old,...., 34 years old.

- Current and historic data on truck populations registered out-of-state but operating in California were required with similar descriptive detail as that provided for in-state populations.

- Historic sales data for California and historic data on the number of HDT's re-registered in California each year disaggregated by weight class and fuel type. These data along with the registration distributions could be used to determine the attrition rate by weight class/fuel type and this could be used with sales forecasts to develop a methodology for estimating future HDT populations in California.

- Data on average annual mileage accrual and average odometer reading (cumulative mileage) disaggregated by weight class, fuel type, and vehicle age.

- Data on the percent of annual mileage driven out-of-state by California registered HDTs and the percent of total HDT VMT accrued by vehicles based outside of California.

- Data on average fuel economy by weight class, fuel type, and age for HDTs operating in California.

- Data on general activity of the California HDT population disaggregated by area of operation, type of use, and ownership.

Unfortunately, a ready source of all of these data does not exist. Much of the data base had to be constructed from various data sources and often estimates of critical parameters were made using the best available California data combined with data for the national HDT fleet. The remainder of this chapter describes the different data sources that were reviewed and summarizes the advantages and disadvantages of each. The chapter concludes with a summary of the data that were actually used in the study. The methods by which these data were used are described in later chapters on the development of population and activity data.

2.1 REVIEW OF DATA SOURCES

ARB Derived 1995 Registration Distributions

This data source is comprised of HDT registration distributions and population data by GVW class, fuel type, and vintage derived by the ARB using a vehicle identification number (VIN) decoding program and registration data provided by DMV. DMV provided an electronic file which included registration records for all trucks registered in California as of the date of the file pass. These records were then VIN decoded and VIN information was compared with other information in the registration record to resolve any anomalies. Thus, a high quality registration file was obtained for analysis purposes. The file provided GVW, fuel type, and fuel vintage detail for 35 vintages for HDTs registered in California in mid-1995. This data source was determined to be the most accurate source on current populations and registration distributions. Unfortunately, DMV does not archive its registration files, so no comparable data were available to the ARB for years prior to 1995. DMV registration data can only be used to analyze populations and registration distributions. No activity data are included.

Truck Inventory and Use Survey (TIUS)

TIUS, developed by the Bureau of Census, is a stratified probability sample of registered trucks across the United States. Sampled trucks are sent a questionnaire and the results are compiled to develop a statistical profile of the nation's trucking fleet. Since the base state of registration for each truck in the sample is provided, a subsample of records representing California registered HDTs can be obtained and used to develop statistical profiles of the state's HDT fleet stratified by GVW class and fuel type. TIUS is executed by the Bureau of Census every five years. Electronic versions of the TIUS files for 1977, 1982, 1987, and 1992 were used in this study.

Population totals, disaggregated by GVW and fuel type, were developed using the 1992 TIUS and compared with totals derived from the DMV current registration files for 1993-1995. These comparisons revealed significant discrepancies in population totals between the two sources. Since TIUS data are derived from a statistical sample and the current DMV registration files use actual registration data, the TIUS data were rejected for use in developing population control totals. However, TIUS was the only source of data which provided historic information on the California HDT population disaggregated by GVW and fuel type. This historic information was used to develop population growth rates which, when applied to the current DMV registration data, could be used to derive historic population totals consistent with the current DMV registration data. In addition, TIUS was the only source of information which provided historic detail by vintage, GVW, and fuel type. These data, when developed using the California TIUS sample, suffered from the problem of small sample sizes. That is, the number of records for a particular vintage, GVW, and fuel type combination in the California sample was generally too small to be considered statistically significant. Historic detail by vintage, GVW, and fuel type at the national level were more robust and trends in the vintage distributions over time at the national level could be used to construct estimates of the historic registration distributions in California. But there are some problems associated with using the TIUS vintage level data that should be noted. TIUS only tracks 11 vintage categories. Since the survey is compiled every five years, this makes it impossible to track the population of a particular model year through more than two consecutive TIUS surveys and does not provide the 35 year vintage detail required for this study. In addition, since TIUS data is developed from a statistical sample, when data are disaggregated by GVW, fuel type, and vintage and populations of a particular model year are tracked through consecutive TIUS surveys, many anomalies can be noted (e.g., populations of a particular model year may actually increase over time). Thus the ARB decided to use the 1995 ARB/DMV registration distribution for all calendar years since that is the only reliable data available at the present time.

TIUS also contains the most comprehensive and consistent data set for analyzing California HDT activity levels as required by this study. The following activity data are provided by TIUS:

- annual mileage accrual rates
- out-of state mileage for California registered HDTs
- cumulative mileage
- fuel economy
- area of operation
- major use
- operator type.

International Registration Plan (IRP) Data

In July 1993, the American Association of Motor Vehicle Administrators adopted the International Registration Plan (IRP) which authorizes the proportional registration of commercial vehicles and provides for the recognition of such registration in participating jurisdictions. Under provisions of federal law, eventually all U.S. states will register interstate carriers under the IRP. IRP data exists at the state level, although in 1991, 21 states contracted the management of this information to Lockheed IMS. Pursuant to work for the South Coast Air Quality Management District (SCAQMD), Lockheed IMS combined their data with information from the remaining IRP states to produce a database of all IRP trucks registered to operate in California. This 1991 unified IRP database provides a snapshot of population and registration distributions of the out-of-state vehicle population operating in California. The IRP data contain GVW, fuel type, and vintage information (0-21 years and a category for vehicles 22 years or older). Unfortunately, this file does not provide any mileage accrual information and it provides no coverage of trip permitted vehicles or trucks operating under interstate reciprocity agreements. California DMV does provide detailed information on IRP registered vehicles that are based in California, including the amount of annual mileage driven within the state. For vehicles based outside of California that operate within California, DMV does compile a recap transmittal summary report. Recap transmittals provide information on the number of vehicles by GVW class operating in California from each state. Unfortunately, the summary reports do not provide information on annual mileage driven.

In summary, the Lockheed IRP database is the best data source on population of out-of-state registered vehicles operating in California. Used in conjunction with survey data collected by Lockheed for the SCAQMD study, it is possible to estimate the population of IRP vehicles actually operating in California averaged over the year and their annual average in-state mileage (see Chapter 4 of this report). The California IRP data available from DMV does not contain sufficient detail for this study. TIUS data is a better source for out-of-state operations of California registered trucks.

CEC's VIN Decoded DMV Registration Data

This is HDT registration data developed by the California Energy Commission (CEC) using current registration files obtained from the DMV. These registration files were similar to those used by the ARB to derive the 1995 registration data described above. In order to ensure proper classification of trucks by weight class, fuel type, and age, CEC used R.L. Polk's VINA program to decode vehicle identification numbers (VIN). CEC staff went to great lengths to resolve anomalies in the database. They did this by comparing registration information and VIN information to flag records with obvious discrepancies. As described above for the ARB derived registration distributions, CEC obtained copies of the DMV registration files for specific points in time. Two file passes were made available, a May 1993 file pass and a May 1994 file pass. CEC acknowledges that each file pass represents a different stage in the development of their "data cleaning" procedures. They believe that there were substantial problems with the 1993 file pass, both because it represented their earliest attempt to process DMV data and because there may have been some underlying problems in the files provided by DMV for that year.[2] CEC believes that the 1994 file pass represents a more accurate depiction of the HDT population registered in California. Given these concerns and the availability of more current (1995) DMV data from the ARB (in which ARB staff had a high degree of confidence), CEC's VIN decoded DMV registration data were not used in the establishment of historic registration distributions or population estimates. As described above in the discussion of the ARB derived 1995 registration files, the CEC derived registration files also did not include any vehicle activity data.

DMV's Gross Report

The DMV's Gross Report is HDT registration data available from the California DMV. It provides monthly snapshots of California's commercial vehicle (and trailer) registrations.

[2]This concern about the quality of the 1993 DMV data was echoed by Caltrans staff.

The report actually consists of three separate reports: the **Body-Type-Model Report** which provides registration data by body type and vehicle configuration; the **Unladen Weight Report** which provides registrations by unladen weight and axle configuration; and the **Motive Power Report** which cross references registrations by body type with fuel type. The most useful of these reports for this study was the Unladen Weight Report. The Report is available for 1985 to the present so it represents one source of historic California registration data. A major drawback of these data are that they provide registrations in terms of unladen weights rather than GVW and dubious extrapolation techniques must be employed when developing GVW class and fuel type detail. When these techniques were used and the populations thus derived were compared with populations by weight class developed using current DMV registration files for the same years, considerable discrepancies were noted. Vintage detail is also not available from the Gross Report. Since the HDT population totals developed using the 1993-1995 current DMV registration files were reasonably consistent from one year to the next and they did provide GVW, fuel type, and vintage detail, the DMV Gross Report data were ultimately rejected in favor of the current DMV registration files.

R.L Polk's TIP System

R.L. Polk uses official title and registration records from states and provinces in its TIP system in order to provide data on new and current registrations. Data can be disaggregated by GVW, fuel type, and vintage as required by this study. Like DMV, Polk provides a snapshot of current registrations and does not archive its data. Therefore, it is impossible to construct historic registration distributions. At the time this study was being conducted, the last renewal file that R.L. Polk had received from California was in 1989. Registration files for subsequent years were estimated based on historic growth rates. Therefore, it was determined that the current registration files from DMV provided a more up-to-date and accurate profile of registration distributions and population.

In addition to information on total HDT registrations by state, R.L. Polk's TIP system provides new registrations data by state, fuel type, GVW class, and other parameters. Although R.L. Polk's data provides fuel type and GVW class detail, it does not differentiate between new sales and new registrations of vehicles previously owned in other states, making it very difficult to use in the analysis of vehicle attrition. In addition, the new registrations data is only available back to calendar year 1985. Given the cost of these data and their limitations, JFA and ARB staff determined that the use of these data were not cost-effective for the current study.

International Fuel Tax Agreement (IFTA)

This is a multi-state and province agreement for sharing fuel tax revenues. The basic purpose is to provide a system to allocate fuel tax revenues according to where vehicle mileage is accrued rather than where fuel is purchased. Carriers are required to submit quarterly apportioned vehicle miles traveled (VMT) reports which provide information on the total miles traveled by all their trucks in each state. For the purposes of this study, IFTA data and other data collected pursuant to fuel tax apportionment, offer little information concerning vehicle populations in California. Since California is not a member of IFTA, then IFTA states are not required to apportion California truck miles. All states were required to join IFTA by 1996, therefore, this data source may prove more useful in future research efforts.

Truck Traffic Count Data

The California Department of Transportation (Caltrans) is the principal agency collecting truck count data across the state. These counts include classification counting which classifies the vehicles primarily by axle configuration, although some counts (weigh-in-motion stations) provide weight data. Caltrans conducts traffic counts only on state highways. This information is maintained in the Traffic Accident Surveillance and Analysis System (TASAS) file. The utilization of traffic counts to derive HDT populations and activity is limited by several factors. While GVW is available in some cases, it is not sufficiently detailed by categories that correspond to ARB weight classes. It is also impossible to determine whether the counts include multiple crossings of the same vehicle. In addition, vehicle fuel type or vintage is not available. These data are further limited since traffic counts are available only for state highways.

State Truck Size and Weight Data

Size and weight violation data are collected at truck weigh stations by trained state officials in each state. Citations are issued for vehicles that are either oversized or overweight. JFA investigated the use of these data for determining the number of out-of-state vehicles operating in California. Since detailed information is collected only on vehicles that are issued citations, size and weight data are limited. The data represent a biased truck sampling as the samples are concerned with the illegal vehicle population and not the legal population. The California Highway Patrol's MISTER file can provide the percentage of drivers with in-state licenses who are issued citations, but it cannot provide information on a vehicle's state of registration.

ARB's Random Roadside Smoke Inspection and Maintenance Program

The ARB administers California's inspection and maintenance program for controlling smoke emissions from diesel HDTs. All trucks operating in the state are subject to inspections, irrespective of the truck's base state. The feasibility of using data on the smoke inspection process to estimate the percentage of HDTs that operate in California but that are base-plated outside the state was investigated. It was found that the feasibility of this approach is compromised by inherent bias attributable to the inspection and maintenance program's structure. The fact that data are only collected on trucks failing metered inspection, raises concerns about extrapolating results to the entire population. Therefore, this data source was eliminated from further consideration.

Other Truck Population Studies for California

In 1985, Pacific Environmental Services (PES) completed a study entitled ***Assessment of Heavy-Duty Gasoline and Diesel Vehicles in California: Population and Use Patterns.*** PES used DMV Gross Report data to estimate the percentage of heavy-duty trucks based in California that drove some mileage outside of the state. The study also used survey data collected by the Interstate Commerce Commission in 1977 to estimate the percentage of heavy truck VMT in California that is attributable to out-of-state registered trucks. PES also used their own truck activity surveys, Caltrans truck count data, and truck counts from the Highway Performance Monitoring System (HPMS) to develop VMT estimates by road type, county, and axle configuration. These data were rejected in the current study because of shortcomings in the methodology for allocating VMT to GVW classes (and the lack of vintage detail in the data) and because the data is out-of-date.

Motor Vehicle Facts and Figures (MVFF)

This annual publication from the American Automotive Manufacturers Association (AAMA) reports new truck registrations by state, but does not provide fuel type or GVW class detail at the state level. However, the ***MVFF*** does provide historic and current information on truck sales by GVW class at the national level that can be used to estimate California HDT sales by fuel type and GVW class.

Caltrans' Motor Vehicle Stock, Travel, and Fuel Forecast (MVSTFF) Model

Currently, the ARB employs data from Caltrans' MVSTFF model for forecasting future truck populations. As the principal state forecasting tool for projecting truck populations and VMT, this source was thoroughly investigated as a potential forecasting methodology for the current study. The MVSTFF process requires twenty-year projections of statewide population, economic growth (expressed in terms of total personal income), vehicle fuel use technologies, inflation, and interest rates in order to develop projections of the total motor vehicle stock. Thus the population and VMT forecasts are driven by economic and demographic variables. Unfortunately, the procedures for forecasting truck stocks and VMT are less robust, assuming that trucks represent a constant fraction of total vehicle population and VMT over time. While the dynamic models that are used to forecast total vehicle stock and VMT have appropriate specifications for projecting light duty vehicle populations and VMT (as a function of variables such as population and personal income) they do not sufficiently reflect the variables that are known to drive heavy truck population and VMT. Thus, this approach was rejected as an option for the HDT forecast methodology required for this study.

2.2 SUMMARY AND CONCLUSIONS

Unfortunately there is no single comprehensive source of data on current and historic HDT populations in California that provides the level of descriptive data that is required for the EMFAC/BURDEN models. In order to obtain population and registration fractions by weight class, fuel type, and age going back 35 calendar years, the historic data needs to be estimated. Baseline population and registration fractions can be obtained from a variety of sources. We believe the most reliable of these is the DMV's own registration records. However, DMV does not archive its registration files so another source needs to be used to construct the historic registration distributions. Of the available sources, only TIUS provides historic data on California populations disaggregated by weight class and fuel type. However, these data are only collected every five years (interim years must be interpolated). Available TIUS files could only be obtained back to 1977, and the population totals are extremely inconsistent with the DMV registration records.

Exhibit 2-1 provides a comparison between the 1992 TIUS data and the 1995 ARB/DMV data that illustrates these inconsistencies. It is interesting to note that in both absolute and relative terms, the largest discrepancy between the two sources is in the light-heavy gasoline category. There may be several explanations of the discrepancies although none of these explanations are conclusive:

- To develop estimates of the light-heavy populations in TIUS it is necessary to apportion TIUS Class II trucks (6,001 lbs. - 10,000 lbs. GVW) above and below the 8,500 lb. cutoff for light-heavy trucks as defined by ARB. The data that were used to develop this apportionment (see Appendix 1) were often missing records in the TIUS sample and the method lacked precision. To the extent that the difference between the two sources is greatest in the light-heavy gasoline class, this approach to apportioning Class II trucks could contribute to the difference.

- TIUS is a survey and the estimates of the California population are developed by expanding the sample data by vehicle category. California trucks are under sampled relative to their contribution to the national truck population (e.g., in 1987 California trucks represented only 2.8 percent of the TIUS sample and 11 percent of the expanded truck population). Even if California were not under sampled, the fact that TIUS is developed from survey data means that there is the potential for inaccuracies based on respondent errors and the general precision of estimates developed from a survey.

- The DMV data may overestimate the population of HDTs in California. Registrations that show no transactions within a 48 month period are supposed to be purged from the DMV database. To the extent that some of these records remain, they will tend to inflate the population totals (although there is no reason to believe *a priori* that these inactive registrations would be concentrated in any one weight class).

Exhibit 2-1
Comparison of 1992 TIUS and 1995 ARB/DMV Registration Data

Vehicle Weight Category	1992 TIUS		1995 ARB	
Light-Heavy Duty Gasoline	97,036	61.6%	281,447	71.9%
Medium-Heavy Duty Gasoline	53,912	34.3%	105,983	27.0%
Heavy-Heavy Duty Gasoline	6,466	4.1%	3,819	1%
Total HDT Gasoline	157,415	37.0%	391,249	59.2%
Light-Heavy Duty Diesel	63,586	23.7%	41,036	15.2%
Medium-Heavy Duty Diesel	69,418	25.9%	141,922	52.6%
Heavy-Heavy Duty Diesel	134,981	50.4%	87,080	32.2%
Total HDT Diesel	267,985	63.0%	270,038	40.8%
Total HDTs	425,400	100%	661,287	100%

- The VIN decoding techniques that are used to resolve data anomalies may result in some trucks being assigned to the light-heavy weight class when they are actually medium-duty trucks, thus inflating the population of light-heavy trucks.

Taking all of these factors into account, we believe that baseline populations developed from DMV registration files are more accurate than those developed from TIUS. However, TIUS can be used to establish trends in populations over time to be applied to a base year population and backcasted (in fact, this turned out to be the only source with GVW and fuel type information that can be used to backcast California HDT populations effectively). Backcasting to 1960 requires further interpolation based on trends from 1977 - 1992.

The California TIUS sample is too small to get any reliable data on historic registration distributions by age. Historic data on vintage distributions for California HDT populations is the greatest weakness in the data needed for this study. Over the long term, greater efforts should be made to develop historic data by archiving DMV registration files.

The best source of information on populations of out-of-state trucks operating in California is the IRP data base developed by Lockheed IMS for SCAQMD. The data provide all of the necessary detail on weight class, fuel type, and age but only one year's data are available. Used in conjunction with the results of the Truck Operations Survey, also conducted by Lockheed for SCAQMD, the IRP data base can help in the estimation of the number of full-time equivalent out-of-state trucks operating in the state at any time. The Truck Operations Survey was conducted using the unified IRP data base as a sampling frame and an extensive data set was collected for trucks operating in the South Coast Air Basin. In this study, this is used as a surrogate for actual data on the amount of VMT traveled in California by out-of-state trucks.

The best approach for estimating California sales data is to apply national sales fractions (by GVW class and fuel type) from ***MVFF*** to total California truck sales (determined using ***MVFF*** and the DMV Gross Report).

All of the activity data used in this study comes from TIUS. This is the most comprehensive source of truck activity data available for California.

In the future, much needs to be done to improve the quality and quantity of data available for analyzing HDT populations in California. DMV registration files should be archived so that within a few years a reliable historic data base can be established and trends in registration distributions can be estimated. In addition, users of HDT registration data (ARB, CEC, Caltrans, DMV) need to come together to resolve discrepancies in the methods used to interpret DMV raw data files and to clean the DMV files. At this point, there is too much discrepancy between the 1993 CEC/DMV data and the 1995 ARB/DMV data to be explained entirely by what actually took place in the truck populations during this period.

3 HEAVY-DUTY TRUCK POPULATIONS

As described in the introduction to this report, the following fleet characterization data are integral to the emissions estimation process employed by the ARB and imbedded in EMFAC:

- historic, current, and future population (or registration) profiles for each combination of GVW class, fuel type (diesel and gasoline), and vintage; and

- current annual mileage accrual rates for each combination of GVW class, fuel type, and vintage.

This chapter focuses on the development of historic-HDT population profiles as required for the construction of emissions estimates via ARB's EMFAC model. Section 3.1 describes the methodology employed to develop the historic population profiles and presents the results of this analysis. Section 3.2 presents estimates of the out-of-state HDT population operating in California at any moment in time. Section 3.3 presents a comparison between the data developed in this project and the data currently in EMFAC/BURDEN. Activity profiles, such as mileage accumulation rates, are the subject of Chapter 4.

3.1 METHODOLOGY TO ESTIMATE HDT POPULATIONS

The focus of much of Task 1, Derivation of HDT Populations, was the development of a methodology to estimate historic and current HDT populations and registration distributions by fuel type, GVW class, and vintage. As discussed above, no direct source of data was available for this purpose. Rather, the development of a methodology was necessary that draws on various data sources to estimate HDT populations for each combination of fuel type, GVW class, and vintage for calendar years 1960 to present. The methodology developed by JFA draws on information available from TIUS and the 1995 ARB/DMV registration files to profile the California registered HDT population and IRP data to profile the out-of-state HDT population operating in California.

The methodology developed by the project team involves the following analytic components:

- estimate HDT populations from 1960 to 1995 by GVW class and fuel type combinations
- estimate historic California specific registration distributions (i.e., the fraction of HDT populations attributable to each vintage by fuel type and GVW class combinations)
- estimate the number of out-of-state HDTs currently operating in California and profile that population by GVW class, fuel type, and vintage.

Each of these analytic components draws on the data sources discussed above, and is further described below.

3.1.1 California Specific HDT Populations

An integral part of this study involves the estimation of total California HDT populations by fuel type and GVW class combination. As shown in Chapter 2, discrepancies in the total population of HDTs are prevalent across data sources. Specifically, HDT population estimates derived from the DMV registration file are much higher than those derived from the TIUS sample or DMV's Gross Report. Since there is no easy way to resolve these discrepancies, the ARB chose to use its 1995 population estimates as the baseline from which historic estimates can be derived. The ARB had confidence in its VIN decoder and methodology for cleaning the data base. Further, the 1995 DMV file was the most current file available and it appeared consistent (in terms of the total HDT population) with 1993 and 1994 file passes performed by the CEC.

This study uses the following approach for estimating California's current and historic HDT fleet by fuel type and GVW class:

- First, ARB's 1995 population data serve as the baseline for the estimation of historic populations.

- Second, TIUS populations for California by fuel type and GVW class are employed to develop historic trends in the population[3]. This was done by curve fitting the five data points, i.e., 1977, 1982, 1987 and 1992 TIUS population results and the 1995 ARB/DMV population result. The equations developed by regressing these five points were then adjusted so that they will give the exact 1995 ARB/DMV population value when evaluated for year 1995. These modified equations are then used to calculate historic populations from 1960 to 1995 calendar years.

Figures 3-1 and 3-2 show the trends in the population growth obtained using regression analysis. Exhibit 3-1 presents the differences between the TIUS derived California HDT populations and those derived via the methodology described above, while Exhibit 3-2 presents the final estimates used in this study for California's HDT population for calendar years 1960 to 1995 (consistent with the 1995 ARB/DMV populations and the growth rates in the California TIUS sample). The expansion factors in Exhibit 3-1 show the extent to which the final population estimates were increased as compared to the original TIUS California samples. These expansion factors were derived by comparing the final population control totals to the original TIUS data.

[3]The TIUS California data were used in this step because they represented the most complete and continuous source of historic data on California HDT populations with weight and fuel type detail. Since the data were not disaggregated by vintage at this stage in the analysis, sample sizes (disaggregated by weight and fuel type only) were sufficiently large to conduct the analysis with California TIUS data.

Exhibit 3-1
Differences between TIUS-Based Population Analysis and Estimates Derived from JFA Methodology

	TIUS				ARB
	1977	1982	1987	1992	1995
LHDG	57,802	77,716	91,714	97,036	281,447
MHDG	101,257	86,369	77,861	53,912	105,983
HHDG	10,026	11,605	2,195	6,466	3,819
Total Gasoline	169,085	173,616	178,611	157,415	391,249
LHDD	1,612	2,804	12,097	63,586	41,036
MHDD	14,591	23,868	41,800	69,418	141,922
HHDD	70,046	95,035	105,923	134,981	87,080
Total Diesel	86,249	121,707	159,820	267,985	270,038
Total HDTs	255,334	295,323	338,431	425,400	661,287

	Estimated				ARB
	1977	1982	1987	1992	1995
LHDG	149,436	171,342	202,428	246,541	281,447
MHDG	122,812	117,792	113,045	108,558	105,983
HHDG	10,722	8,804	6,887	4,969	3,819
Total Gasoline	282,969	297,938	322,360	360,068	391,249
LHDD	1622	3,979	9,762	23,950	41,036
MHDD	37,649	48,773	69,091	106,207	141,922
HHDD	53,888	63,108	72,328	81,548	87,080
Total Diesel	93,159	115,859	151,181	211,704	270,038
Total HDTs	376,128	413,797	473,541	571,772	661,287
Expansion Factor	1.47	1.40	1.40	1.34	1.00

Fig. 3-1
Estimated HDT Populations by Fuel / Weight Category - Gasoline

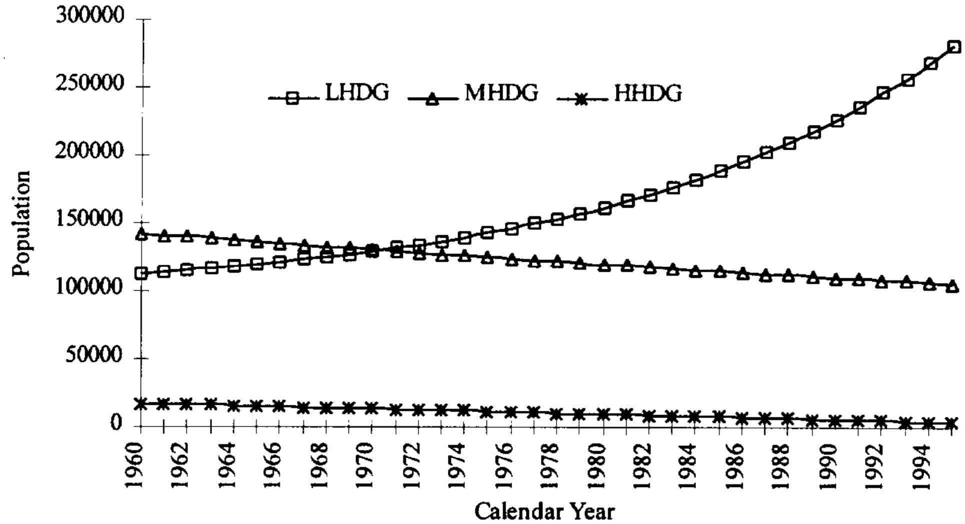


Fig. 3-2
Estimated HDT Populations by Fuel / Weight Category - Diesel

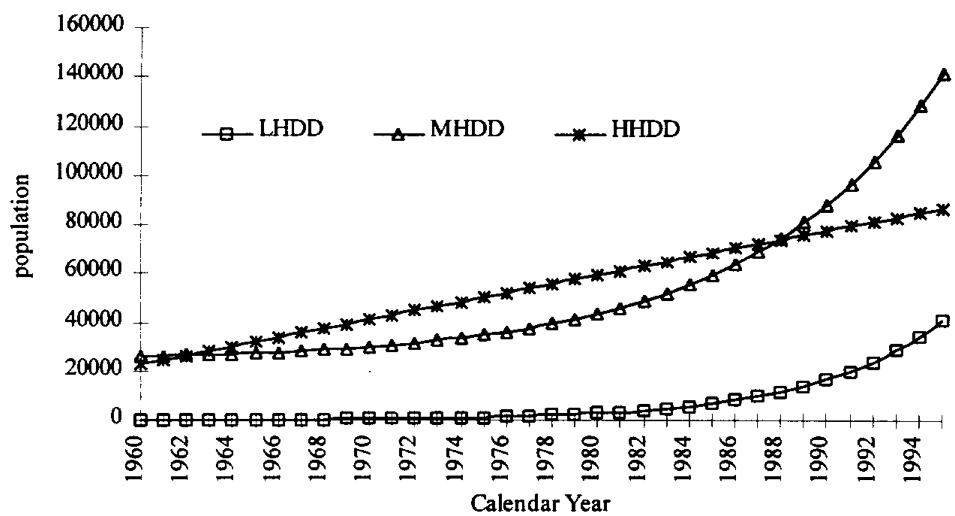


EXHIBIT 3-2
Estimated HDT Populations by Fuel type and GVW Class

Calendar Year	LHDG	MHDG	HHDG	LHDD	MHDD	HHDD
1995	281447	105983	3819	41036	141922	87080
1994	268988	106832	4202	34293	128557	85236
1993	257372	107690	4586	28658	116710	83392
1992	246541	108558	4969	23950	106207	81548
1991	236442	109435	5353	20014	96897	79704
1990	227026	110323	5736	16726	88643	77860
1989	218246	111220	6120	13978	81327	76016
1988	210060	112128	6503	11681	74841	74172
1987	202428	113045	6887	9762	69091	72328
1986	195311	113974	7270	8158	63994	70484
1985	188676	114912	7654	6817	59476	68640
1984	182489	115861	8037	5697	55471	66796
1983	176720	116821	8421	4761	51920	64952
1982	171342	117792	8804	3979	48773	63108
1981	166327	118773	9188	3325	45982	61264
1980	161651	119766	9571	2779	43509	59420
1979	157291	120770	9955	2322	41316	57576
1978	153226	121785	10338	1941	39372	55732
1977	149436	122812	10722	1622	37649	53888
1976	145902	123850	11105	1355	36122	52044
1975	142607	124899	11489	1133	34768	50200
1974	139535	125961	11872	946	33567	48356
1973	136670	127035	12256	791	32503	46512
1972	133999	128120	12639	661	31560	44668
1971	131509	129218	13023	552	30724	42824
1970	129187	130329	13406	462	29983	40980
1969	127022	131451	13789	386	29325	39136
1968	125003	132587	14173	322	28743	37292
1967	123121	133735	14556	269	28226	35448
1966	121366	134896	14940	225	27769	33604
1965	119730	136070	15323	188	27363	31760
1964	118204	137258	15707	157	27003	29916
1963	116782	138459	16090	131	26684	28072
1962	115455	139673	16474	110	26402	26228
1961	114219	140901	16857	92	26151	24384
1960	113066	142143	17241	77	25929	22540

3.1.2 California Specific HDT Registration Distributions

The only data source that provides historic information by vintage, GVW and fuel is TIUS. Unfortunately, this data source could not be used to determine registration distribution for this project because several problems were noted when these data was analyzed by age, GVW and fuel for the California sample. First, when TIUS data for California trucks was disaggregated by weight class, fuel type, and vintage, the resulting sample size was too small to be statistically significant. Second, since TIUS is conducted every five years and only tracks 11 vintage categories, it was impossible to track the population of a particular model year through more than two TIUS surveys and did not provide the 35 year vintage required by this study. Because of these limitations and weaknesses with the TIUS data, the ARB decided to use the 1995 ARB/DMV population distribution for all calendar years since that is the only reliable California specific data available at present that gives vintage from 0 to 34 years.

Exhibit 3-3 and Exhibit 3-4 show the 1995 registration distribution. The 1995 ARB/DMV registration distribution provides the percent of trucks in each weight class/fuel type category attributable to each model year (MY) going back to model year 1960 (the percentage for 1960 is the percentage of trucks with MY 1960 or earlier).

Comparison of New Registration Distributions with Those in the Current Version of EMFAC/BURDEN Version 7G - ARB staff provided JFA with a document entitled "Derivation of Emission and Correction Factors for EMFAC7G," prepared by the Mobile Source Division, Motor Vehicle Analysis Branch, which includes information on data in the current version of EMFAC/BURDEN. This allowed for selected comparisons between the newly derived registration distributions and those already in the model.

JFA compared the diesel and gasoline registration fractions in the current version of the model with the 1995 distributions developed for this study. Figure 3-3 illustrates the cumulative registration distributions from EMFAC as compared to the new registration distributions for diesel trucks. It shows that the two distributions are reasonably similar. In general, the registration distribution for the data developed in this study shows a slightly older fleet than does that of the current version of EMFAC. Figure 3-3 shows that until a vintage of 12 years old, there is a higher percentage of trucks in the EMFAC diesel distribution than in the new data. The distribution also shows that 100% of the diesel fleet is 24 years old or younger in the EMFAC distribution whereas only 96.6% of the diesel fleet is 24 years or younger in the new data.

While the cumulative registration distributions for the diesel fleet in 1995 were similar, they are very different for gasoline trucks. Fig. 3-4, shows that the new distribution is characterized by a much older fleet than the current version of the model. For example, the current version of the model indicates that about 35% of gasoline trucks are 4 years old or younger, whereas less than 10% of the new distribution's gasoline trucks are this young. In addition, the new data has a significant population of gasoline trucks that are 25 years old or older (10%). The registration distribution in the current distribution of

Exhibit 3-3
1995 California HDV Registration by Vintage - Diesel

Vintage	Total HDDVs	% of Total	Total LHDDV	% of Total	Total MHDDV	% of Total	Total HHDDV	% of Total
0	11,038	4.09%	1,145	2.79%	6,875	4.84%	3,018	3.47%
1	12,690	4.70%	2,714	6.61%	6,846	4.82%	3,130	3.59%
2	12,968	4.80%	3,499	8.53%	6,696	4.72%	2,773	3.18%
3	12,487	4.62%	3,037	7.40%	6,846	4.82%	2,604	2.99%
4	15,168	5.62%	3,230	7.87%	8,264	5.82%	3,674	4.22%
5	21,957	8.13%	4,532	11.04%	11,550	8.14%	5,875	6.75%
6	20,207	7.48%	4,010	9.77%	9,196	6.48%	7,001	8.04%
7	17,657	6.54%	3,200	7.80%	8,521	6.00%	5,936	6.82%
8	17,425	6.45%	3,184	7.76%	8,291	5.84%	5,950	6.83%
9	17,021	6.30%	4,551	11.09%	6,633	4.67%	5,837	6.70%
10	16,353	6.06%	2,781	6.78%	6,870	4.84%	6,702	7.70%
11	15,028	5.57%	2,261	5.51%	6,380	4.50%	6,387	7.33%
12	7,806	2.89%	1,812	4.42%	2,916	2.05%	3,078	3.53%
13	7,341	2.72%	927	2.26%	3,103	2.19%	3,311	3.80%
14	8,376	3.10%	91	0.22%	4,239	2.99%	4,046	4.65%
15	7,940	2.94%	7	0.02%	5,507	3.88%	2,426	2.79%
16	9,379	3.47%	5	0.01%	6,113	4.31%	3,261	3.74%
17	6,613	2.45%	7	0.02%	4,334	3.05%	2,272	2.61%
18	5,021	1.86%	8	0.02%	3,129	2.20%	1,884	2.16%
19	3,067	1.14%	4	0.01%	2,025	1.43%	1,038	1.19%
20	3,501	1.30%	4	0.01%	2,191	1.54%	1,306	1.50%
21	3,907	1.45%	10	0.02%	2,666	1.88%	1,231	1.41%
22	3,556	1.32%	4	0.01%	2,316	1.63%	1,236	1.42%
23	2,556	0.95%	1	0.00%	1,706	1.20%	849	0.97%
24	1,735	0.64%	1	0.00%	1,228	0.87%	506	0.58%
25	1,698	0.63%	1	0.00%	1,254	0.88%	443	0.51%
26	1,465	0.54%	1	0.00%	1,147	0.81%	317	0.36%
27	820	0.30%	5	0.01%	675	0.48%	140	0.16%
28	550	0.20%	6	0.01%	397	0.28%	147	0.17%
29	340	0.13%	0	0.00%	261	0.18%	79	0.09%
30	268	0.10%	0	0.00%	221	0.16%	47	0.05%
31	223	0.08%	0	0.00%	176	0.12%	47	0.05%
32	135	0.05%	0	0.00%	115	0.08%	20	0.02%
33	137	0.05%	0	0.00%	116	0.08%	21	0.02%
34+	3,607	1.34%	0	0.00%	3,119	2.20%	488	0.56%
Total	270,040	100.00%	41,038	100.00%	141,922	100.00%	87,080	100.00%

EXHIBIT 3-4
1995 California HDV Registration by Vintage - Gasoline

Vintage	Total HDGVs	% of Total	Total LHDGV	% of Total	Total MHDGV	% of Total	Total HHDGV	% of Total
0	3,614	0.92%	2,510	0.89%	1,103	1.04%	1	0.03%
1	8,862	2.27%	6,876	2.44%	1,984	1.87%	2	0.05%
2	7,552	1.93%	5,787	2.06%	1,757	1.66%	8	0.21%
3	7,094	1.81%	5,221	1.86%	1,869	1.76%	4	0.10%
4	9,609	2.46%	6,733	2.39%	2,865	2.70%	11	0.29%
5	13,709	3.50%	9,743	3.46%	3,960	3.74%	6	0.16%
6	15,161	3.88%	11,277	4.01%	3,867	3.65%	17	0.45%
7	14,915	3.81%	11,196	3.98%	3,701	3.49%	18	0.47%
8	15,593	3.99%	11,941	4.24%	3,642	3.44%	10	0.26%
9	17,511	4.48%	13,984	4.97%	3,502	3.30%	25	0.65%
10	18,942	4.84%	14,708	5.23%	4,190	3.95%	44	1.15%
11	19,240	4.92%	15,817	5.62%	3,400	3.21%	23	0.60%
12	12,500	3.19%	10,535	3.74%	1,949	1.84%	16	0.42%
13	11,390	2.91%	9,206	3.27%	2,152	2.03%	32	0.84%
14	11,785	3.01%	8,803	3.13%	2,917	2.75%	65	1.70%
15	13,153	3.36%	9,319	3.31%	3,769	3.56%	65	1.70%
16	28,511	7.29%	22,319	7.93%	6,100	5.76%	92	2.41%
17	26,602	6.80%	21,571	7.66%	4,931	4.65%	100	2.62%
18	24,656	6.30%	20,183	7.17%	4,396	4.15%	77	2.02%
19	16,093	4.11%	12,381	4.40%	3,630	3.43%	82	2.15%
20	13,304	3.40%	8,273	2.94%	4,885	4.61%	146	3.82%
21	10,031	2.56%	5,227	1.86%	4,675	4.41%	129	3.38%
22	13,269	3.39%	7,465	2.65%	5,636	5.32%	168	4.40%
23	11,089	2.83%	6,328	2.25%	4,607	4.35%	154	4.03%
24	7,985	2.04%	4,446	1.58%	3,394	3.20%	145	3.80%
25	7,993	2.04%	4,229	1.50%	3,633	3.43%	131	3.43%
26	7,284	1.86%	3,866	1.37%	3,303	3.12%	115	3.01%
27	5,388	1.38%	2,897	1.03%	2,393	2.26%	98	2.57%
28	6,725	1.72%	4,834	1.72%	1,799	1.70%	92	2.41%
29	4,863	1.24%	3,772	1.34%	1,023	0.97%	68	1.78%
30	270	0.07%	0	0.00%	114	0.11%	156	4.08%
31	264	0.07%	0	0.00%	117	0.11%	147	3.85%
32	235	0.06%	0	0.00%	93	0.09%	142	3.72%
33	370	0.09%	0	0.00%	214	0.20%	156	4.08%
34+	5,687	1.45%	0	0.00%	4,413	4.16%	1,274	33.36%
Total	391,249	100.00%	281,447	100.00%	105,983	100.00%	3,819	100.00%

EMFAC only extends to 25 years and less than 1% of the gasoline trucks in this distribution are 25 years or older.

Another comparison that was made between the two distributions was the fuel specific weight class population distribution. With respect to weight class distribution, the current version of the model and the distributions developed for this study show similar percentages of the diesel fleet in the heavy-heavy weight class (32.2% in the new distribution and 37.5% in the current version of EMFAC). However, the two distributions show significant divergence with respect to the distribution of diesel trucks across the light-heavy and medium-heavy weight classes. The distributions developed for this project show 15.2% of diesel trucks in the light-heavy class and 52.6% in the medium-heavy class whereas the current version of EMFAC shows 33.6% of diesel trucks in the light-heavy class and 29.0% in the medium-heavy class.

There are also differences in the gasoline distributions across weight class. The current version of EMFAC assumes that all gasoline trucks are in either the light-heavy or medium-heavy class. This assumption is in reasonable agreement with the distributions developed for this study which include only 1.0% of the gasoline trucks in the heavy-heavy class. As in the case of diesel trucks, the distribution of gasoline trucks developed for this study tends to be skewed towards the heavier weight classes with 71.9% of the trucks in the light-heavy class and 27.1% in the medium-heavy class as compared to 81.2% of trucks in the light-heavy class and 18.8% in the medium-heavy class in the current version of EMFAC.

3.1.3 Methodology to Estimate Out-of-State HDTs

This sub-section presents the results of the IRP-based methodology to estimate out-of-state HDT populations by fuel type, GVW class, and vintage. First, data are provided on the universe of HDTs that are licensed to operate in California. Second, estimates are derived of the equivalent full-time out-of-state HDT population operating in California and associated activity. This step is vital to an emissions estimating procedure that calculates HDT contributions on a daily or yearly basis. The data sets employed to derive estimates of the out-of-state full-time equivalent on-road HDT population by fuel type, GVW class, and vintage are: Lockheed IMS IRP database, results of SCAQMD's "Truck Operations Survey Results" and DMV's Fee-Paid Vehicle Report. The analysis results in a 1991 snapshot of this population.

Lockheed IMS IRP Registration Database: Exhibits 3-5 and 3-6 report registration distributions for both gas and diesel IRP trucks registered for operation in California. The vast majority of IRP registered trucks are diesel vehicles. Only 9,421 trucks were gasoline powered, while 330,889 vehicles were diesel powered. All of out-of-state registered diesel truck population were over 33,000 lbs GVW.

Fig. 3-3
Cumulative Registration Fractions - Diesel

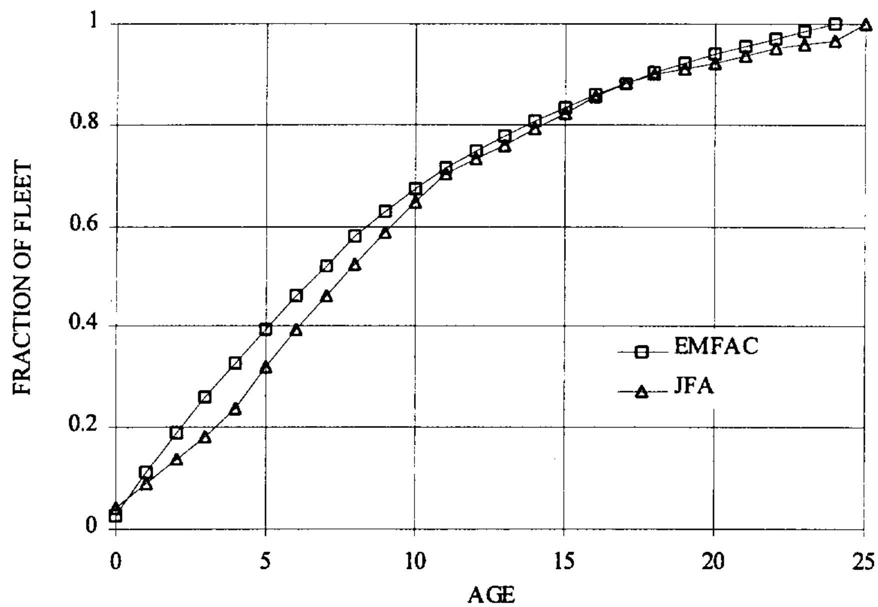
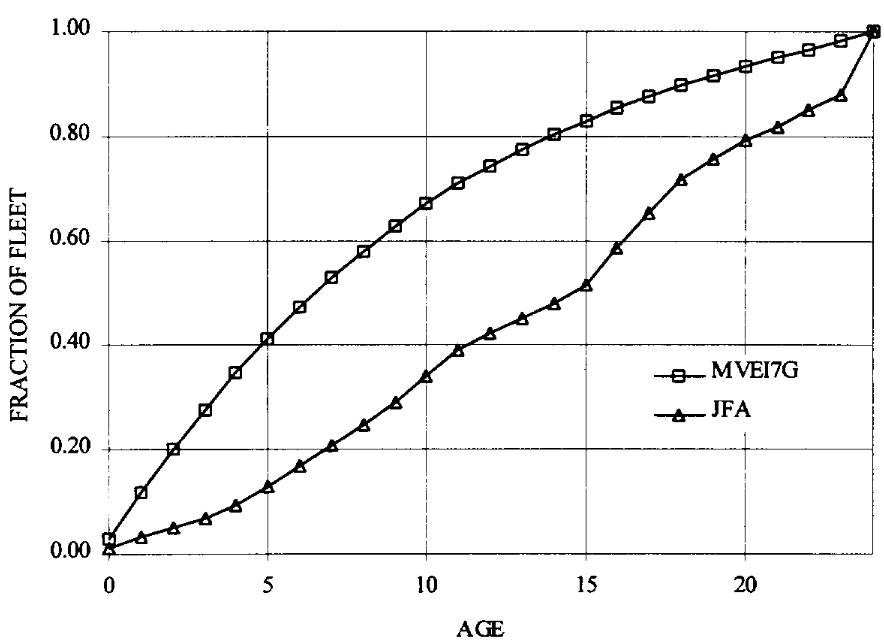


Fig. 3-4
Cumulative Registration Fractions - Gasoline



The Lockheed IMS IRP database provides information on the number of out-of-state trucks which are registered to operate in California, but provides no data on the amount or proportion of mileage these vehicles accrue in the state. Two specific pieces of information were needed to address this. First, an estimate of the average daily on -road truck population was required. This estimate would provide the full time equivalent out-of-state vehicle population. Additionally, data on the average mileage accrual of these full time equivalent vehicles was needed.

Estimated On-Road Population The percentage of interstate truck activity occurring in California was estimated using data from SCAQMD's "Truck Operations Survey Results"[4] report. This research focused specifically on truck activity in the South Coast Air Basin, but sheds light on truck activity at the state level as well.

The study found that a population of 292,235 IRP trucks operated in the South Coast Air Basin in 1991.[5] The report also estimated that of those trucks that reported operating some mileage in the basin in the previous year, 54,209, or about 18.5%, operated there on a typical day.[6] Exhibit 3-7 summarizes the results of Exhibits 3-5 and 3-6 and scales the registered population into an estimated on-road population using the 18.5% factor. This assumes that the relationship between the IRP population operating in the South Coast Air Basin and the on-road population is the same as the relationship between those registered to operate in California and the on-road population of the state. The data show that there are 63,109 full time equivalent HDV's operating in California.

Out-of-State Fee Paid Vehicles IRP trucks are only a subset of the total out-of-state vehicle population. A number of vehicles operate with trip permits or are from other non-IRP states. Exhibit 3-8 reports data from California DMV's Fee Paid Vehicle report. The Fee Paid Vehicle report provides estimates of the total number of out-of-state vehicles paying fees in California. This data shows that 448,259 out-of-state vehicles paid fees in California in 1991. Approximately 107,939 non-IRP vehicles operated in the state in that year. Exhibit 3-8 also shows a substantial increase in the operation of out-of-state vehicles in the state. From 1990 to 1993, the population increased by almost 80,000. This explosive growth can be explained by many different factors. The rise of this population may reflect an increase in inter-state commerce or the growth of trucking at the expense of other transportation modes. The growth of the IRP and the reduced regulatory burden on inter-state carriers that it provides for may also have encouraged carriers to report mileage and pay fees that were avoided before. Large interstate companies re-basing their vehicles outside of the state may also have increased the number of out-of-state trucks. Assuming the same distribution by fuel - weight class as

[4] Truck Operations Survey Results. South Coast Air Quality Management District, March 1993

[5] Truck Operations Survey Results. Table 41, p.67

[6] Truck Operations Survey Results. Table 45, p.72

the IRP vehicles, Exhibit 3-9 shows the distribution by weight class and fuel of all out-of-state vehicles paying fees in California.

Out-of-State HDT Populations by Fuel Type, GVW Class, and Vintage (1991)- Exhibits 3-10 and 3-11 disaggregate the 1991 total and on-road population of DMV fee paid vehicles using the registration distribution of IRP vehicles shown in exhibits 3-5 and 3-6. It should be noted that the daily on-road population is 18.5% of what is shown in Exhibits 3-5 and 3-6. The central assumption to this methodology is that the types and ages of vehicles operating interstate are likely to be the same, whether they are registered under the IRP or operate under some other authority.

Exhibit 3-5
1991 IRP Gasoline Registration Distribution.

	Total	Percent of Total	Population and % GVW Class					
Vintage	Population	Population	8,500 - 14,000		14,001 - 33,000		> 33,000	
0	234	2.48	37	0.96	54	1.71	143	5.97
1	337	3.58	46	1.19	91	2.89	200	8.35
2	1091	11.58	97	2.51	776	24.60	218	9.10
3	792	8.41	146	3.77	376	11.92	270	11.27
4	265	2.81	81	2.09	83	2.63	101	4.22
5	385	4.09	66	1.70	186	5.90	133	5.55
6	446	4.73	57	1.47	179	5.68	210	8.76
7	303	3.22	49	1.27	145	4.60	109	4.55
8	172	1.83	25	0.65	62	1.97	85	3.55
9	175	1.86	17	0.44	61	1.93	97	4.05
10	200	2.12	18	0.46	71	2.25	111	4.63
11	195	2.07	30	0.77	96	3.04	69	2.88
12	1,725	18.31	1,381	35.68	209	6.63	135	5.63
13	1,005	10.67	815	21.05	110	3.49	80	3.34
14	791	8.40	633	16.35	100	3.17	58	2.42
15	406	4.31	299	7.72	60	1.90	47	1.96
16	144	1.53	8	0.21	79	2.50	57	2.38
17	145	1.54	19	0.49	75	2.38	51	2.13
18	152	1.61	20	0.52	84	2.66	48	2.00
19	102	1.08	8	0.21	56	1.78	38	1.59
20	77	0.82	4	0.10	43	1.36	30	1.25
21	49	0.52	3	0.08	25	0.79	21	0.88
22+	230	2.44	12	0.31	133	4.22	85	3.55
Total	9,421	100%	3,871	100%	31,54	100%	2,396	100%

Source: Lockheed IMS IRP database

Exhibit 3-6
1991 IRP Diesel Registration Distribution.

Vintage	Total Population	Percent of Total Population	Population and % GVW Class 8,500 - 14,000		14,001 - 33,000		> 33,000	
0	36,196	10.94	378	4.83	3,932	7.55	31,886	11.77
1	39,708	12.00	1,009	12.90	6,761	12.98	31,938	11.79
2	50,500	15.26	924	11.82	7,169	13.76	42,407	15.65
3	37,950	11.47	759	9.71	5,751	11.04	31,440	11.60
4	32,329	9.77	611	7.81	5,438	10.44	26,280	9.70
5	25,925	7.83	727	9.30	5,820	11.17	19,378	7.15
6	26,580	8.03	665	8.50	4,765	9.15	21,150	7.80
7	20,224	6.11	780	9.98	3,164	6.07	16,280	6.01
8	7,860	2.38	387	4.95	1,198	2.30	6,275	2.32
9	7,534	2.28	144	1.84	1,218	2.34	6,172	2.28
10	7,861	2.38	126	1.61	995	1.91	6,740	2.49
11	7,541	2.28	141	1.80	1,328	2.55	6,072	2.24
12	8,854	2.68	246	3.15	1,327	2.55	7,281	2.69
13	6,093	1.84	220	2.81	1,038	1.99	4,835	1.78
14	4,343	1.31	144	1.84	561	1.08	3,638	1.34
15	1,991	0.60	73	0.93	266	0.51	1,652	0.61
16	1,691	0.51	43	0.55	171	0.33	1,477	0.55
17	2,079	0.63	79	1.01	314	0.60	1,686	0.62
18	1,862	0.56	100	1.28	327	0.63	1,435	0.53
19	1,176	0.36	112	1.43	154	0.30	910	0.34
20	639	0.19	40	0.51	80	0.15	519	0.19
21	493	0.15	27	0.35	90	0.17	376	0.14
22+	1,470	0.44	84	1.07	218	0.42	1,168	0.43
Total	330,899	100%	7,819	100%	52,085	100%	270,995	100%

Source: Lockheed IMS IRP database

Exhibit 3-7
Out-of-State IRP Registered and Estimated On-Road Population

Vehicle Class	IRP Registered to Operate in California				Estimated On-Road population			
	Gasoline		Diesel		Gasoline		Diesel	
	Pop.	%	Pop.	%	Pop.	%	Pop.	%
8,500 - 14,000	3,871	41.09%	7,819	2.36%	718	41.09%	1,450	2.36%
14,001 - 33,000	3,154	33.48%	52,085	15.74%	585	33.48%	9,659	15.74%
> 33,000	2,396	25.43%	270,995	81.90%	444	25.43%	50,254	81.90%
All HDVs	9,421	100%	330,889	100%	1,747	100%	61,362	100%

Exhibit 3-8
Out-of-State Fee Paid Vehicles

Calendar Year	Total Number of Trucks	Calendar Year (Continued)	Total Number of Trucks
1993	561,168	1976	79,020
1992	494,037	1975	75,359
1991	448,259	1974	64,886
1990	480,023	1973	68,617
1989	367,952	1972	61,050
1988	439,989	1971	57,142
1987	341,324	1970	56,944
1986	344,182	1969	39,458
1985	378,065	1968	27,889
1984	165,689	1967	32,757
1983	186,989	1966	23,606
1982	146,481	1965	24,596
1981	130,854	1964	18,651
1980	139,113	1963	18,084
1979	120,369	1962	16,081
1978	104,083	1961	13,734
1977	72,836	1960	13,273

Exhibit 3-9
Out-of-State Fee-Paid Registered and Estimated On-Road Population

	Fee Paid Out-of-State Registered (1991)				Estimated On-Road population			
	Gasoline		Diesel		Gasoline		Diesel	
Vehicle Class	Pop.	%	Pop.	%	Pop.	%	Pop.	%
8,500 - 14,000	5,099	41%	10,299	2%	943	41%	1,905	2%
14,001 - 33,000	4,154	33%	68,605	16%	768	33%	12,692	16%
> 33,000	3156	25%	356,946	82%	584	25%	66,035	82%
All HDVs	12,409	100%	435,850	100%	2,296	100%	80,632	100%

Exhibit 3-10
1991 Out-of-State HDV Population by Vintage - Gasoline

Vintage	Total On-Road HDGVs	% of Total	Total On-Road LHDGV	% of Total	Total On-Road MHDGV	% of Total	Total On-Road HHDGV	% of Total
0	308	2.48	49	0.96	71	1.71	188	5.97
1	444	3.58	61	1.19	120	2.89	263	8.35
2	1,437	11.58	128	2.51	1,022	24.60	287	9.10
3	1,043	8.41	192	3.77	495	11.92	356	11.27
4	349	2.81	107	2.09	109	2.63	133	4.22
5	507	4.09	87	1.70	245	5.90	175	5.55
6	587	4.73	75	1.47	236	5.68	277	8.76
7	399	3.22	65	1.27	191	4.60	144	4.55
8	227	1.83	33	0.65	82	1.97	112	3.55
9	231	1.86	22	0.44	80	1.93	128	4.05
10	263	2.12	24	0.46	94	2.25	146	4.63
11	257	2.07	40	0.77	126	3.04	91	2.88
12	2,272	18.31	1,819	35.68	275	6.63	178	5.63
13	1,324	10.67	1,073	21.05	145	3.49	105	3.34
14	1,042	8.40	834	16.35	132	3.17	76	2.42
15	535	4.31	394	7.72	79	1.90	62	1.96
16	190	1.53	11	0.21	104	2.50	75	2.38
17	191	1.54	25	0.49	99	2.38	67	2.13
18	200	1.61	26	0.52	111	2.66	63	2.00
19	134	1.08	11	0.21	74	1.78	50	1.59
20	101	0.82	5	0.10	57	1.36	40	1.25
21	65	0.52	4	0.08	33	0.79	28	0.88
22	65	0.52	4	0.08	36	0.86	25	0.79
23	49	0.39	5	0.10	32	0.76	12	0.38
24	38	0.31	1	0.02	21	0.51	16	0.50
25	26	0.21	1	0.02	16	0.38	9	0.29
26	19	0.15	1	0.02	9	0.22	9	0.29
27	26	0.21	1	0.02	20	0.48	5	0.17
28	13	0.10	1	0.02	8	0.19	4	0.13
29	13	0.10	0	0.00	5	0.13	8	0.25
30	2	0.02	0	0.00	1	0.03	1	0.03
31	4	0.03	0	0.00	3	0.06	1	0.03
32	5	0.04	0	0.00	5	0.13	1	0.03
33	7	0.06	0	0.00	3	0.06	4	0.13
34+	34	0.29	0	0.00	17	0.41	17	0.54
Total	12,409	100.0	5,099 41.09	100.0	4,154 33.48	100.00	3,156 25.43	100.00

Exhibit 3-11
1991 Out-of-State HDV Population by Vintage - Diesel

Vintage	Total On-Road HDDVs	% of Total	Total On-Road LHDDV	% of Total	Total On-Road MHDDV	% of Total	Total On-Road HHDDV	% of Total
0	47,676	10.94	498	4.83	5,179	7.55	41,999	11.77
1	52,302	12.00	1,329	12.90	8,905	12.98	42,068	11.79
2	66,517	15.26	1,217	11.82	9,443	13.76	55,857	15.65
3	49,987	11.47	1,000	9.71	7,575	11.04	41,412	11.60
4	42,583	9.77	805	7.81	7,163	10.44	34,615	9.70
5	34,148	7.83	958	9.30	7,666	11.17	25,524	7.15
6	35,010	8.03	876	8.50	6,276	9.15	27,858	7.80
7	26,638	6.11	1,027	9.98	4,168	6.07	21,444	6.01
8	10,353	2.38	510	4.95	1,578	2.30	8,265	2.32
9	9,924	2.28	190	1.84	1,604	2.34	8,130	2.28
10	10,354	2.38	166	1.61	1,311	1.91	8,878	2.49
11	9,933	2.28	186	1.80	1,749	2.55	7,998	2.24
12	11,662	2.68	324	3.15	1,748	2.55	9,590	2.69
13	8,026	1.84	290	2.81	1,367	1.99	6,369	1.78
14	5,720	1.31	190	1.84	739	1.08	4,792	1.34
15	2,622	0.60	96	0.93	350	0.51	2,176	0.61
16	2,227	0.51	57	0.55	225	0.33	1,945	0.55
17	2,738	0.63	104	1.01	414	0.60	2,221	0.62
18	2,453	0.56	132	1.28	431	0.63	1,890	0.53
19	1,549	0.36	148	1.43	203	0.30	1,199	0.34
20	842	0.19	53	0.51	105	0.15	684	0.19
21	649	0.15	36	0.35	119	0.17	495	0.14
22	519	0.12	30	0.29	83	0.12	406	0.11
23	373	0.09	26	0.26	99	0.14	248	0.07
24	219	0.05	16	0.15	24	0.03	179	0.05
25	191	0.04	11	0.10	30	0.04	150	0.04
26	126	0.03	11	0.10	7	0.01	109	0.03
27	80	0.02	4	0.04	4	0.01	72	0.02
28	61	0.01	3	0.03	8	0.01	50	0.01
29	49	0.01	1	0.01	7	0.01	41	0.01
30	51	0.01	3	0.03	9	0.01	40	0.01
31	34	0.01	1	0.01	1	0.00	32	0.01
32	26	0.01	1	0.01	3	0.00	22	0.01
33	31	0.01	1	0.01	1	0.00	29	0.01
34+	179	0.04	5	0.05	13	0.02	161	0.05
Total	435,850	100.00	10,299 2.36	100.00	68,605 15.74	100.00	356,946 81.90	100.00

3.2 METHODOLOGY FOR FORECASTING FUTURE HDT POPULATIONS

In discussions with ARB staff, JFA learned that existing forecasts of HDT populations rely to some extent on projections developed by Caltrans using the MVSTFF model described in Chapter 2 of this report. Therefore, JFA began its search for a forecast methodology with MVSTFF.

MVSTFF forecasts truck populations as a fraction of the total vehicle stock. Total vehicle stock is computed as a function of human population, licensed drivers per household, and income per person. The parameters of this equation have been estimated econometrically. The population forecast for each truck class is then determined by applying the base year splits to the forecasted population.

JFA rejected this approach because it assumes that all classes of vehicles experience the same rate of population growth (clearly an inaccurate assumption) and because the economic/demographic variables used to project vehicle stock have little to do with demand for trucking.

As an alternative, JFA attempted to use the historic population data developed in this study to estimate attrition rates and the historic sales data to develop sales growth rates. Due to lack of California specific data by fuel and weight class the results of this methodology are not included in this report, In addition, the ARB is already in the process of developing forecasting methodologies for heavy-duty trucks which will be consistent with forecasting methodologies for light-duty vehicles and medium-duty trucks. The ARB has already developed forecasting methodologies for light-duty vehicles and medium-duty trucks which will be incorporated in future versions (beyond 7G) of the emissions inventory model.

It should be noted that, the CEC is in the process of upgrading its freight energy demand model with funding from ARB. The current CEC model forecasts truck stocks based on VMT projections and historical average VMT per vehicle data. VMT forecasts for long haul trucks are based on ton-mile projections derived from economic projections of freight transportation demand by industry sector. Since it would be desirable in the long-run to develop a truck stock model that forecasts future truck stock based on a combination of economic variables, policy variables, and technology variables (as these all impact new sales rates and vehicle retirement rates), it is in ARB's best interest to continue working with CEC to develop an upgraded forecasting capability.

3.3 SUMMARY AND CONCLUSIONS, HDT POPULATION DATA

This chapter discussed the results of JFA's efforts to develop new population data for next revision of MVEI7G. A number of significant issues regarding population data were discussed and are summarized below.

- ***The best available source of current population data disaggregated by weight class, fuel type, and vintage is the DMV registration file.*** Both CEC and ARB now receive copies of the current DMV registration files. CEC reports that the data that is provided by DMV needs further cleaning. Inactive registrations are not always purged from the data base and there are apparent anomalies (vehicle weight designations do not match known information about the weight classes of particular makes and models, for example). ***A consistent set of procedures and protocols should be developed for data cleanup so that a single clean DMV registration file can be made available to all potential users.*** In addition, ARB's Mobile Source Division and CEC each use different VIN decoding programs to process DMV registration files. ***Sources of inconsistency between these VIN decoders need to be better understood and documented so that discrepancies between data analysis conducted with the different VIN decoders can be explained.***

- Since DMV registration files have not been archived there is no consistent and comprehensive source of historic California registration distributions and population data with full weight class, fuel type, and ***vintage*** detail. The California sub-sample within TIUS suffers from the problem of small sample sizes when it is disaggregated to provide vintage detail. ***Therefore, the best approach to developing historic California populations is to assume that rates of change in the registration distribution at the national level are the same as those for California. These changes in distributions can then be applied to an initial distribution from DMV records to derive a unique historic California distribution.*** Even though this is the best approach given available data, it is not without problems. Since TIUS only provides 10 vintages and the survey is only conducted every five years, it is impossible to track a given model year through more than two TIUS samples before it becomes part of the "10+" vintage. This also makes it impossible to develop a distribution that links populations of a given model year from one calendar year to the next. The result is that populations of a particular model year may grow and decline over time in ways that do not always make sense. To some extent this is due to anomalies in the underlying population distributions for the national TIUS data while to some extent it is a result of having to mix and match data from different sources. ***In the long run, analysis of California HDT population data would be greatly enhanced by archiving DMV registration files to produce a consistent historic data set with full vintage detail.***

- There is significant disagreement between TIUS and DMV registration files as to what the California population of HDTs actually is. ***TIUS appears to substantially underestimate HDT populations in California.***

- ***The registration fractions for diesel vehicles developed in this study appear to be reasonably consistent with current EMFAC distributions.*** In the late vintages (vehicles 5 years old or younger) the existing EMFAC distributions may show a greater percent of the population than the new distributions. However, beyond that period the existing EMFAC distribution may show a slightly older fleet than the new distribution. ***The registration fractions for gasoline vehicles show a substantial difference between the new data and the EMFAC data.*** The new distributions present a much older fleet mix than what is currently in EMFAC.

- ***Diesel distributions across truck weight classes show a skew towards more medium-heavy trucks at the expense of light-heavy trucks for the new distributions as compared to the distributions currently in EMFAC.*** Other aspects of the weight/fuel type distributions developed in this project are more consistent with the current EMFAC data.

- The unified IRP data base developed by Lockheed IMS and the truck operations study in the South Coast Air Basin also conducted by Lockheed provide the best estimate of out-of-state populations operating in the state. ***Additional survey work conducted through roadside interviews with follow-up phone surveys could be conducted throughout the state in order to determine if the data from the South Coast Air Basin is actually representative.***

4 HEAVY-DUTY TRUCK ACTIVITY

Activity data is an important input to accurately estimate heavy duty vehicle emissions. Section 4.1 provides a review of the data used to produce the activity statistics under this section. The section also describes some of the limitations of the data and the methodologies which were used to compensate for these limitations. Section 4.2 presents data on each activity variable at both the California and the National level. Data on annual mileage accrual rates, cumulative mileage, fuel economy, area of operation, major use, jurisdiction and operator type are presented.

4.1 DATA AND METHODOLOGY

Truck activity data for California was obtained from the 1992 TIUS. Due to the lack of vintage detail at the state level (sample sizes at this level of disaggregation are too small to produce statistically significant results), average odometer readings (cumulative mileage) and average annual mileage accrual by vintage for California were estimated by adjusting national estimates to reflect California specific populations. These estimates were derived through the following steps.

1. Average in-state mileage accrual rates for California registered trucks by weight class/fuel type from TIUS were applied to California registered truck population totals by weight class/fuel type from TIUS to get a first estimate of VMT from California registered trucks by weight class/fuel type.

2. An adjustment factor was developed based on the ratio of California populations by weight class/fuel type developed for this study (see Chapter 3) to the California populations by weight class/fuel type from TIUS. This adjustment factor was multiplied by the VMT estimates to get new control totals for VMT by weight class/fuel type for California that are consistent with the population estimates derived for this study.

3. Mileage accrual rates by GVW/fuel class/vintage were calculated at the National level using TIUS data. The ratio of the mileage accrual rate for each vintage to the average mileage accrual rate for each weight class/fuel type category at the National level was used to develop factors for distributing the mileage accrual rates by vintage. These distributions were applied to the average mileage accrual rates by weight class/fuel type for California registered trucks calculated in Step 1 above to get mileage accrual rates by vintage for California.

4. The mileage accrual rates calculated in Step 3 above were multiplied by the California population distributions developed for this study (Chapter 3) to get VMT by weight class/fuel type/vintage and this was summed across vintages to get VMT by weight/class fuel type. This estimate was compared with the control totals calculated in Step 2 above and the vintage-specific mileage accrual rates were then scaled so that the two estimates of California VMT would match (i.e., when VMT by vintage was summed it would equal the control totals for VMT by weight class/fuel type calculated in Step 2 above).

4.2 ACTIVITY VARIABLES

4.2.1 Annual Mileage

To obtain an estimate of annual mileage accrual TIUS asks, "How many miles has this vehicle driven in 1992". Respondents reported between 0 and 332,205 miles of annual mileage accrual for their vehicles. Figure 4-1 and Exhibit 4-1 show annual in-state VMT by GVW category and fuel type for California registered HDTs. A majority of the heavy duty vehicle VMT is for diesel HHDT's. Of the 9,283 million VMT driven by California registered heavy duty vehicles, 3,399 million, or about 37%, was driven by diesel vehicles over 33,000 lbs GVW. The VMT figures shown are expanded VMT, while the N shown is the number of records which were used to represent the truck population.

Figure 4-2 and Exhibit 4-2 report the average in-state annual mileage accrual rate for heavy duty vehicles. The data show that gasoline vehicles have a lower average in-state accrual rate than diesel vehicles. HDT gas vehicle annual mileage averaged 6,563 - 11,591 miles for all three GVW classes. Reflecting the fact that they tend to be more heavily engaged in for-hire, long haul trucking, the heaviest class of diesel vehicles averaged 41,685 miles per year. California's heavy-heavy duty diesel vehicles had lower average annual mileage accrual rates than the national population which averaged 50,773 miles per year.

To obtain an estimate of the percent of mileage a truck traveled outside of its state of registration, TIUS asks, "What percent of annual mileage was traveled outside of the base state?". By multiplying this percentage by the annual mileage of a vehicle, an estimate of the number of miles traveled outside of the state was obtained. Exhibit 4-3 and Exhibit 4-4 show out-of-state miles traveled by vehicles registered in California, but operating some of their mileage in other states.

Due to the small number of gas heavy duty vehicles in the sample for California, there were no trucks in the survey which represented heavy-heavy duty gas vehicles traveling interstate.

Comparison with national data show that the number of these vehicles is very low nationwide. For gas powered trucks, most out-of-state mileage is driven by vehicles under 33,000 lbs. GVW. This use pattern is reversed for diesel powered trucks. The data show that in California, 63.90% of out-of-state mileage is driven by heavy-heavy duty trucks. The national percentage is higher. The data show that about 90.01% of national inter-state truck VMT is driven by the heaviest class of trucks.

Exhibit 4-5 summarizes the results of Exhibit 4-1, Exhibit 4-3 and Exhibit 4-4. This table shows that in general, California vehicles tend to travel a smaller percentage of their mileage out-of-state than the national truck population. California data shows a lower percentage of mileage driven out-of-state for all vehicle classes with the exception of medium heavy duty gas vehicles. This trend may be due to the fact that California is a larger state and would allow for a larger scale of intra-state operations.

Exhibit 4-1
California - Annual In-State VMT by Vehicle Class (In Millions of Miles)

Vehicle Class	GAS		DIESEL	
	VMT	N	VMT	N
8,500 - 14,000	2,858	77	413	73
14,001 - 33,000	712	76	1,855	231
> 33,000	45	11	3,399	960
All HDVs	3,615	164	5,668	1,264

Fig. 4-1: California In-State VMT in Millions

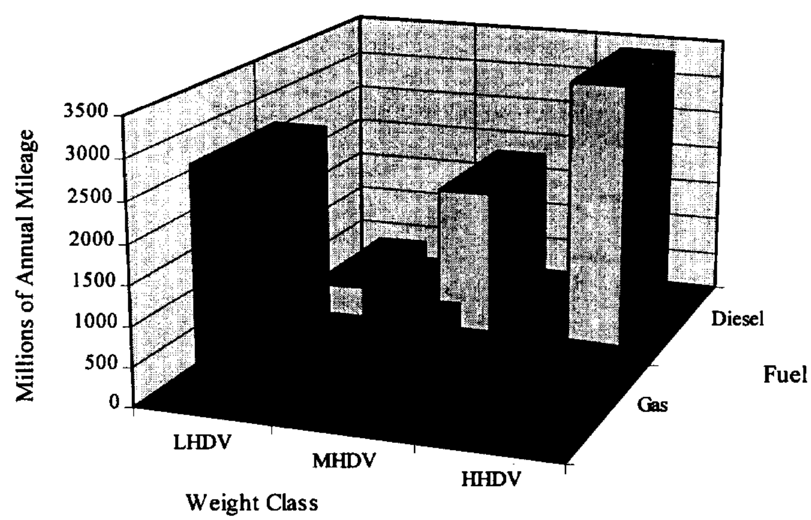
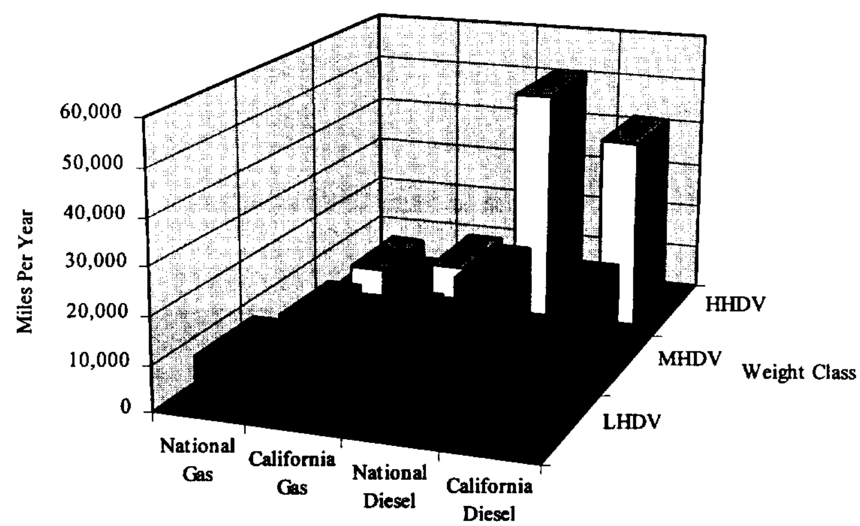


Exhibit 4-2
Annual Average In-State Mileage Accrual Rate by Vehicle Class (in Miles)

Vehicle Class	CALIFORNIA				NATIONAL			
	GAS		DIESEL		GAS		DIESEL	
	VMT	N	VMT	N	VMT	N	VMT	N
8,500 - 14,000	11,591	77	17,259	73	10,261	6,430	19,191	2,342
14,001 - 33,000	6,563	76	17,465	231	6,603	8,767	19,389	9,789
> 33,000	8,983	11	41,685	960	6,604	1,996	50,733	50,995
All HDVs	10,039	164	26,771	1,264	8,325	17,193	38,677	63,126

Fig. 4-2: Average Annual In-State Mileage Accrual Rates



For emissions purposes, mileage driven by a newer vintage vehicle can have a substantially different impact than mileage driven by older vehicles. Exhibit 4-6 provides in-state annual mileage accrual rates for diesel and gas HDT's by vintage and weight class. The annual mileage accrual rate by vintage for vintages 0-9 was obtained from 1992 TIUS. For vintages 10-34 no detail was provided in the 1992 TIUS. The 1977 TIUS was the last survey to obtain mileage accrual rates for all vintages. JFA computed the ratio of each 10+ vintage's mileage accrual rate to the weighted average for all 10+ vintages in 1977 and these ratios were applied for vehicles 10 years old or older. Exhibit 4-7 shows the total (in-state plus the out of state) average annual mileage accrual rate for California vehicles.

Exhibit 4-3
Gas vehicle Out-of-State Annual VMT

Vehicle Class	CALIFORNIA		NATIONAL	
	Millions of VMT	Percent	Millions of VMT	Percent
8,500 - 14,000	48	24.29%	483	48.58%
14,001 - 33,000	149	75.71%	488	49.09%
> 33,000	0	0.00%	23	2.32%
All HDVs	197	100.00%	995	100.00%

Exhibit 4-4
Diesel vehicle Out-of-State Annual VMT

Vehicle Class	CALIFORNIA		NATIONAL	
	Millions of VMT	Percent	Millions of VMT	Percent
8,500 - 14,000	31	6.27%	446	1.51%
14,001 - 33,000	19	3.97%	1,616	5.47%
> 33,000	437	89.75%	27,505	93.03%
All HDVs	487	100.00%	29,567	100.00%

Exhibit 4-5
Percent of Mileage Traveled Outside of the Base State

Vehicle Class	CALIFORNIA		NATIONAL	
	GAS	DIESEL	GAS	DIESEL
8,500 - 14,000	1.65%	6.88%	4.95%	8.37%
14,001 - 33,000	17.31%	1.03%	7.77%	12.65%
> 33,000	0.00%	11.39%	2.99%	36.07%
All HDVs	5.17%	7.91%	5.91%	31.34%

Exhibit 4-6
1992 California Annual In-State Mileage Accrual Rate By Vintage

Vintage	LHDGVs	MHDGVs	HHDGVs	LHDDVs	MHDDVs	HHDDVs
0	17628	11381	51371	22170	21241	70418
1	19293	16562	96094	23018	24666	76570
2	23378	12247	47157	22959	27891	75795
3	21713	11783	35151	22938	23459	74189
4	20115	10879	78445	22549	23298	67153
5	18331	16440	45281	20347	20511	57584
6	15297	13076	41630	22181	20925	54342
7	19386	11039	60947	15801	21153	52853
8	17442	14494	42321	13908	21075	48587
9	15309	10815	22158	11672	19469	42996
10	11736	6018	25186	9074	15891	28369
11	11317	5820	24189	8703	15265	27305
12	10898	5700	23192	8332	14638	26241
13	10479	5516	22195	7960	14011	25177
14	10059	5332	21198	7589	13384	24113
15	9640	5147	20201	7218	12757	23049
16	9221	4963	19204	6846	12130	21985
17	8802	4778	18208	6475	11503	20921
18	8383	4594	17211	6104	10876	19857
19	7964	4410	16214	5733	10249	18793
20	7545	4225	15217	5361	9622	17729
21	7125	4041	14220	4990	8995	16665
22	6706	3856	13223	4619	8368	15601
23	6287	3672	12226	4247	7741	14537
24	5868	3488	11229	3876	7114	13473
25	5449	3303	10232	3505	6487	12409
26	5030	3119	9236	3133	5860	11345
27	4611	2935	8239	2762	5233	10281
28	4191	2750	7242	2391	4606	9217
29	3772	2566	6245	2020	3979	8153
30	3353	2381	5248	1648	3352	7089
31	2934	2197	4251	1277	2725	6025
32	2515	2013	3254	906	2098	4961
33	2096	1828	2257	534	1471	3897
34	1677	1644	1261	163	845	2833

Exhibit 4-7
1992 California Annual Mileage (In-State + Out-of-State) Accrual Rate By Vintage

Vintage	LHDGVs	MHDGVs	HHDGVs	LHDDVs	MHDDVs	HHDDVs
0	17924	13763	51371	23809	21463	79473
1	19616	20029	96094	24718	24924	86416
2	23769	14810	47157	24656	28182	85542
3	22077	14249	35151	24633	23704	83730
4	20452	13157	78445	24216	23541	75789
5	18638	19881	45281	21851	20725	64989
6	15553	15814	41630	23820	21144	61330
7	19711	13350	60947	16968	21373	59649
8	17734	17528	42321	14936	21295	54835
9	15565	13080	22158	12535	19672	48525
10	11933	7278	25186	9745	16057	32017
11	11506	7039	24189	9346	15424	30816
12	11080	6894	23192	8947	14790	29615
13	10654	6671	22195	8549	14157	28414
14	10228	6448	21198	8150	13523	27214
15	9802	6225	20201	7751	12890	26013
16	9376	6002	19204	7352	12256	24812
17	8949	5779	18208	6954	11623	23611
18	8523	5556	17211	6555	10989	22410
19	8097	5333	16214	6156	10356	21209
20	7671	5110	15217	5757	9722	20009
21	7245	4887	14220	5359	9089	18808
22	6819	4664	13223	4960	8455	17607
23	6392	4441	12226	4561	7822	16406
24	5966	4218	11229	4162	7188	15205
25	5540	3995	10232	3764	6555	14005
26	5114	3772	9236	3365	5921	12804
27	4688	3549	8239	2966	5288	11603
28	4262	3326	7242	2567	4654	10402
29	3835	3103	6245	2169	4021	9201
30	3409	2880	5248	1770	3387	8000
31	2983	2657	4251	1371	2754	6800
32	2557	2434	3254	973	2120	5599
33	2131	2211	2257	574	1487	4398
34	1705	1988	1261	175	853	3197

4.2.2 Cumulative Mileage

Vintage specific cumulative mileage is calculated by using vintage specific in-state and out of state accrual rates. For each vintage the cumulative mileage is equal to the sum of all accrual rates from vintage 0 up to the current vintage. Exhibit 4-8 shows the resulting cumulative mileage.

4.2.3 Comparisons of New Mileage Data with EMFAC7G

Several comparisons were possible between the newly developed activity data and that which is in the current version of the motor vehicle emission inventory models. First a comparison was made of the percent of diesel HDT VMT by weight class for the two data sources. Since the new data is based on the 1992 TIUS, the distribution for 1992 is used for comparison purposes. In the current version of the model, 66% of diesel HDT VMT is attributed to heavy-heavy trucks, 19% is attributed to medium-heavy trucks, and 15% is attributed to light-heavy trucks. In the data developed for this study, 75.2% of the diesel HDT VMT is attributed to heavy-heavy trucks, 20.5% to medium-heavy trucks, and 4.3% to light-heavy trucks. Thus, the new distribution shows more VMT from the heaviest weight classes.

Annual mileage accrual rates from the current model were compared with mileage accrual rates developed for this study. These data are compared in Exhibits 4-9, 4-10, 4-11, and 4-12. While there is no clear trend in these charts, it appears that overall mileage accrual rates are higher in the new data as are cumulative mileage for most classes of trucks. This could result in higher emission inventories from trucking overall.

4.2.4 Average Annual Mileage for Out-of- State Trucks

TIUS gives only the percent of VMT traveled out of the base state but does not provide the state or states where this out of state travel is occurring. Thus it is not possible to directly estimate the amount of travel from out-of-state trucks operating in California and therefore an assumption has to be made to estimate this level of travel. One assumption that could be made is that the out-of-state trucks operating in California accrue the same mileage on California highways as do all California registered trucks. According to this assumption, Exhibit 4-13 provides estimates of the 1991 mileage accumulation for out-of-state vehicles. These estimates are obtained multiplying the in-state accrual rate for each vehicle class given in Exhibit 4-2 by the corresponding estimated on-road population given in Exhibit 3-9. From the results, it can be determined that the percent of travel from out-of-state trucks is about 24.60% of the total VMT traveled in California. Previous analysis of the 1982 TIUS survey conducted by Sierra Research, Inc.[7] for the

[7] Analysis of the 1982 Truck Inventory and Use Survey, Data for California, p.46.

Exhibit 4-8
1992 California Cumulative Mileage by Vintage

Vintage	LHDGVs	MHDGVs	HHDGVs	LHDDVs	MHDDVs	HHDDVs
0	17,924	13,763	51,371	23,809	21,463	79,473
1	37,539	33,792	147,465	48,527	46,386	165,889
2	61,308	48,602	194,621	73,183	74,569	251,431
3	83,385	62,851	229,772	97,816	98,273	335,160
4	103,837	76,008	308,217	122,031	121,814	410,949
5	122,475	95,890	353,499	143,882	142,540	475,938
6	138,028	111,704	395,129	167,701	163,683	537,268
7	157,739	125,054	456,076	184,669	185,056	596,918
8	175,473	142,582	498,396	199,606	206,351	651,752
9	191,038	155,661	520,554	212,140	226,023	700,277
10	202,971	162,939	545,740	221,885	242,080	732,294
11	214,477	169,978	569,929	231,231	257,504	763,110
12	225,557	176,871	593,120	240,178	272,295	792,725
13	236,211	183,542	615,316	248,727	286,452	821,140
14	246,439	189,990	636,514	256,877	299,975	848,354
15	256,241	196,214	656,715	264,628	312,865	874,366
16	265,617	202,216	675,919	271,980	325,121	899,178
17	274,566	207,995	694,127	278,934	336,744	922,790
18	283,090	213,550	711,338	285,489	347,733	945,200
19	291,187	218,883	727,551	291,645	358,089	966,409
20	298,858	223,993	742,768	297,402	367,811	986,418
21	306,102	228,880	756,988	302,761	376,900	1,005,226
22	312,921	233,544	770,211	307,721	385,356	1,022,833
23	319,313	237,984	782,438	312,282	393,178	1,039,239
24	325,280	242,202	793,667	316,445	400,366	1,054,444
25	330,820	246,197	803,899	320,208	406,921	1,068,449
26	335,934	249,969	813,135	323,573	412,842	1,081,253
27	340,622	253,518	821,374	326,540	418,130	1,092,855
28	344,883	256,844	828,615	329,107	422,784	1,103,257
29	348,719	259,947	834,860	331,276	426,805	1,112,459
30	352,128	262,827	840,108	333,046	430,192	1,120,459
31	355,111	265,484	844,360	334,417	432,946	1,127,259
32	357,668	267,918	847,614	335,390	435,067	1,132,857
33	359,799	270,129	849,871	335,963	436,554	1,137,255
34	361,504	272,117	851,132	336,139	437,407	1,140,452

ARB, showed that the percent of travel from out-of-state trucks to be 20% of the total VMT which is close to the result of this study. While mileage accumulation is spread fairly evenly among gasoline trucks, approximately 92% of diesel mileage is driven by heavy-heavy trucks. Diesel vehicles also account for the vast majority of the total mileage. Approximately 91% of all out-of-state mileage is driven by heavy diesel trucks.

Exhibit 4-9
Comparison of Annual Mileage Accrual Rates - Diesel Trucks

	LHDD		MHDD		HHDD	
AGE	JFA	ARB	JFA	ARB	JFA	ARB
0	22170	18352	21241	45544	70418	82288
1	23018	16946	24666	39671	76570	74984
2	22959	15648	27891	34558	75795	68328
3	22938	14449	23459	30092	74189	62263
4	22549	13342	23298	26213	67153	56737
5	20347	12320	20511	22834	57584	51700
6	22181	11376	20925	19898	54342	47111
7	15801	10540	21153	17332	52853	42930
8	13908	9700	21075	15098	48587	39119
9	11672	8956	19469	13152	42996	35647
10	9074	8270	15891	11456	28369	32483

Exhibit 4-10
Comparison of Annual Mileage Accrual Rates - Gasoline Trucks

	LHDG		MHDG	
AGE	JFA	ARB	JFA	ARB
0	17628	18211	11381	20032
1	19293	16767	16562	18444
2	23378	15437	12247	16981
3	21713	14213	11783	15634
4	20115	13086	10879	14395
5	18331	12048	16440	13253
6	15297	11093	13076	12202
7	19386	10213	11039	11234
8	17442	9403	14494	10343
9	15309	8657	10815	9523
10	11736	7971	6018	8768

Exhibit 4-11
Comparison of Cumulative Mileage -- Diesel Trucks

AGE	LHDD		MHDD		HHDD	
	JFA	ARB	JFA	ARB	JFA	ARB
0	23809	10525	21463	18063	79473	46796
1	48527	21049	46386	36126	165889	93592
2	73183	65596	74569	51661	251431	145911
3	97816	102402	98273	72385	335160	205663
4	122031	161199	121814	98826	410949	248014
5	143882	80458	142540	132423	475938	289173
6	167701	224701	163683	132423	537268	335443
7	184669	117474	185056	212100	596918	351403
8	199606	180842	206351	200599	651752	344865
9	212140	196776	226023	261268	700277	379344
10	221885	298872	242080	282245	732294	395288

Exhibit 4-12
Comparison of Cumulative Mileage - Gasoline Trucks

AGE	LHDG		MHDG	
	JFA	ARB	JFA	ARB
0	17924	10025	13763	13016
1	37539	20050	33792	26032
2	61308	32704	48602	29859
3	83385	43317	62851	47959
4	103837	51795	76008	55714
5	122475	62399	95890	67867
6	138028	75104	111704	80472
7	157739	79818	125054	85573
8	175473	88521	142582	84703
9	191038	87852	155661	92736
10	202971	107085	162939	100348

Exhibit 4-13
Annual VMT for Out-Of-State Registered Trucks in Millions of Miles

Vehicle Class	GAS		DIESEL	
	VMT	%	VMT	%
8,500 - 14,000	11	51.53%	33	1.09%
14,001 - 33,000	5	23.77%	222	7.37%
> 33,000	5	24.70%	2753	91.54%
All HDVs	21	100%	3007	100%

4.2.5 Fuel Economy

Exhibit 4-14 provides comparative data on the average fuel economy of heavy duty vehicles in California and in the U.S. as a whole. California diesel vehicles average fuel economy is 6.47 miles per gallon, in comparison national fuel economy of the average truck is 6.69 mpg.

ARB had expressed an interest in obtaining data on the variation in truck fuel economy by age. Unfortunately, California data disaggregated to this level of detail is not statistically significant. Exhibits 4-15 and 4-16 show national average fuel economy by vehicle age.

Exhibit 4-14
Mean MPG by Vehicle Class

Vehicle Class	CALIFORNIA				NATIONAL			
	GAS		DIESEL		GAS		DIESEL	
	MPG	N	MPG	N	MPG	N	MPG	N
8,500 - 14,000	6.56	77	6.63	73	7.58	6040	9.99	2173
14,001 - 33,000	7.02	76	7.84	231	7.00	8317	7.75	8866
> 33,000	10.25	11	5.74	960	6.19	1895	5.68	50300
All HDVs	6.87	1644	6.47	1264	7.23	16252	6.69	61339

Exhibit 4-15
National Diesel Vehicle Average MPG by Vintage

Vintage	8501 - 14000		14001 - 33000		Over 33000	
	MPG	N	MPG	N	MPG	N
0	11.52	288	8.34	497	6.09	3651
1	11.59	210	8.27	465	6.08	2911
2	8.50	282	8.43	563	6.00	3270
3	10.21	281	8.22	491	5.80	4054
4	11.41	191	8.21	594	5.79	3819
5	11.33	153	8.35	608	5.80	3710
6	11.12	175	8.22	675	5.79	3062
7	10.74	117	8.00	552	5.65	3089
8	11.60	90	7.46	559	5.54	3204
9	11.52	61	7.57	290	5.44	1456
10+	6.67	319	6.71	3487	5.42	17668

Exhibit 4-16
National Gasoline Vehicle Average MPG by Vintage

Vintage	8501 - 14000		14001 - 33000		Over 33000	
	MPG	N	MPG	N	MPG	N
0	7.06	108	8.29	45	5.81	4
1	7.15	159	8.76	92	8.21	8
2	7.83	208	6.82	91	7.99	11
3	9.15	273	7.14	133	5.33	11
4	6.79	326	7.64	142	6.79	13
5	9.01	268	6.22	161	7.20	19
6	5.98	326	7.46	184	7.98	18
7	7.89	303	7.00	203	8.59	27
8	6.85	233	7.61	151	5.78	27
9	7.64	137	5.99	116	5.33	23
10+	7.72	3673	6.99	6919	6.05	1720

4.2.6 Area of Operation

To measure truck area of operation, TIUS reports the percent of mileage operated in each of six categories. TIUS asks what percentage of a truck's annual miles were operated off road as well as what percentage of mileage was operated with trips in five different distance categories. For instance TIUS asks, "What percentage of this vehicle's annual miles were accounted for by trips less than 50 miles from the vehicle's home base" and "What percent of this vehicles annual mileage was accounted for by trips between 50 and 100 miles from the vehicles home base". From these six questions, TIUS provides a derived variable which classifies vehicles into the area of operation category in which they operate most of their miles.

Exhibits 4-17 through 4-20 show the distribution of California and National vehicle populations according to their area of operation classification. For both National and California, and for both gas and diesel vehicle populations, the most prevalent area of operation is 0-50 miles. With the exception of the heaviest class of vehicles, over 50% of all trucks were classified as local (0-50 mile) vehicles.

Even among the heavy-heavy duty vehicles, a substantial percentage of trucks were classified as shorthaul. Forty one percent of California heavy-heavy diesel vehicles were classified as shorthaul. At the national level, this percentage was somewhat lower, approximately 37%. The sparsity of observations makes the data for California gas HHDTs suspect. TIUS shows only 9.54% of these trucks operating as short haul vehicles. National data estimate that approximately 76% of these trucks are short haul.

The only category of vehicles which had a substantial number of trucks operating very long haul (over 500 miles) were heavy-heavy diesel vehicles. Approximately 11% of California HHDV's were classified as very long haul. The national population included more very long haul vehicles, approximately 17% of the heaviest diesel vehicles were classified as such.

Exhibit 4-17
California Gasoline Vehicle Area of Operation by GVW Class

Area of Operation: Greatest % of Mileage	8,500 - 14,000		14,001 - 33,000		Over 33,000	
	%	N	%	N	%	N
Off Road	3.45	3	11.79	9	0.00	0
0 - 50 miles	58.11	42	62.69	46	9.54	2
50 - 100 miles	17.37	16	20.87	11	0.00	0
100 - 200 miles	6.90	6	0.00	0	49.98	4
200 - 500 miles	0.00	0	4.66	3	40.47	5
Over 500 miles	14.18	2	0.00	0	0.00	0
Total	100.00	69	100.00	69	100.00	11

Exhibit 4-18
California Diesel Vehicle Area of Operation by GVW Class

Area of Operation: Greatest % of Mileage	8,500 - 14,000		14,001 - 33,000		Over 33,000	
	%	N	%	N	%	N
Off Road	3.00	5	5.34	17	3.35	28
0 - 50 miles	56.44	43	56.85	105	41.61	316
50 - 100 miles	17.52	15	26.73	55	24.41	213
100 - 200 miles	4.29	4	9.13	16	15.94	139
200 - 500 miles	18.74	1	1.96	6	14.68	137
Over 500 miles	0.00	0	0.71	4	11.11	110
Total	100.00	68	100.00	199	100.00	833

Exhibit 4-19
National Gasoline Vehicle Area of Operation by GVW Class

Area of Operation: Greatest % of Mileage	8,500 - 14,000		14,001 - 33,000		Over 33,000	
	%	N	%	N	%	N
Off Road	8.49	688	14.84	1,459	12.32	321
0 - 50 miles	69.66	4,550	71.32	6,113	76.84	1,459
50 - 100 miles	13.60	776	9.85	744	8.29	137
100 - 200 miles	3.87	197	2.11	180	1.72	34
200 - 500 miles	1.57	66	1.05	77	0.63	18
Over 500 miles	2.81	49	0.83	46	0.21	9
Total	100.00	6,326	100.00	8,619	100.00	1,978

Exhibit 4-20
National Diesel Vehicle Area of Operation by GVW Class

Area of Operation: Greatest % of Mileage	8,500 - 14,000		14,001 - 33,000		Over 33,000	
	%	N	%	N	%	N
Off Road	3.38	103	6.04	790	4.20	2,330
0 - 50 miles	57.81	1,325	57.56	5,226	37.04	16,963
50 - 100 miles	22.70	477	21.70	1,869	16.39	8,509
100 - 200 miles	6.08	160	7.82	798	11.11	5,936
200 - 500 miles	6.85	70	4.01	451	13.49	7,304
Over 500 miles	3.17	125	2.87	324	17.78	9,777
Total	100.00	2,260	100.00	9,458	100.00	50,819

4.2.7 Major Use

Heavy duty vehicles are employed for a variety of uses including for-hire transportation, construction, agriculture, mining, manufacturing, retail, and business services. To measure the type of vehicle use, TIUS asks, "Which of the following best describes your business or the part of your business in which the vehicle was used?" Exhibits 4-21 through 4-24 describe the major use of gas and diesel vehicles in both California and at the national level. Truck use varies significantly for the gas and diesel vehicle populations. Gas HDT's are more likely to be used for personal transportation and agriculture. Gas LHDT's are the only class of vehicles which report a substantial number of trucks used for personal transportation. TIUS reports that 16.42% of California gas LHDT's are used primarily for personal transportation. The national figure is slightly lower at 11.53%.

Exhibit 4-21
California Gasoline Vehicle Major Use by GVW Class

	8,500 - 14,000		14,001 - 33,000		Over 33,000	
Major Use	%	N	%	N	%	N
Agricultural	8.68%	9	13.35%	11	24.41%	4
Forestry	1.07%	1	0.57%	1	0.00%	0
Construction	13.92%	13	19.20%	16	0.00%	0
Contractor/Trades	4.40%	5	17.56%	13	36.90%	3
Manufacturing	2.14%	2	5.78%	3	0.00%	0
Wholesale	7.49%	7	6.57%	5	16.07%	1
Retail	8.56%	8	9.63%	5	1.79%	1
Business Service	19.75%	9	7.92%	5	4.77%	1
Utilities	1.07%	1	3.85%	2	0.00%	0
Mining	1.07%	1	0.00%	0	0.00%	0
Daily Rental	3.21%	3	0.00%	0	0.00%	0
Not in Use	7.93%	9	6.85%	8	0.00%	0
For Hire	4.28%	4	4.85%	5	16.07%	1
Other	0.00%	0	0.00%	0	0.00%	0
One-way Rental	0.00%	0	0.00%	0	0.00%	0
Personal Trans.	16.42%	5	3.85%	2	0.00%	0
Total	100.00%	77	100.00%	76	100.00%	11

Exhibit 4-22
California Diesel Vehicle Major Use by GVW Class

Major Use	8,500 - 14,000 %	8,500 - 14,000 N	14,001 - 33,000 %	14,001 - 33,000 N	Over 33,000 %	Over 33,000 N
Agricultural	27.17%	7	7.05%	18	8.87%	97
Forestry	0.00%	0	0.17%	1	3.11%	25
Construction	4.91%	6	11.81%	26	13.95%	104
Contractor/Trades	8.48%	8	4.71%	9	1.28%	15
Manufacturing	0.97%	2	5.72%	18	5.90%	64
Wholesale	6.18%	8	15.70%	33	7.67%	83
Retail	9.62%	8	12.09%	18	5.85%	60
Business Service	33.83%	16	9.65%	19	7.85%	65
Utilities	1.63%	1	4.66%	7	0.40%	3
Mining	0.18%	1	0.00%	0	0.97%	8
Daily Rental	0.00%	0	6.16%	8	1.91%	19
Not in Use	2.60%	11	7.05%	34	2.11%	23
For Hire	4.42%	5	15.25%	40	40.12%	394
Other	0.00%	0	0.00%	0	0.00%	0
One-way Rental	0.00%	0	0.00%	0	0.00%	0
Personal Trans.	0.00%	0	0.00%	0	0.00%	0
Total	100.00%	73	100.00%	231	100.00%	960

Exhibit 4-23
National Gasoline Vehicle Major Use by GVW Class

Major Use	8,500 - 14,000 %	8,500 - 14,000 N	14,001 - 33,000 %	14,001 - 33,000 N	Over 33,000 %	Over 33,000 N
Agricultural	17.52%	1,152	40.24%	3,664	55.56%	1,114
Forestry	1.38%	95	1.98%	209	3.32%	62
Construction	9.67%	695	12.62%	1,144	15.69%	314
Contractor/Trades	10.83%	763	8.48%	655	4.93%	90
Manufacturing	3.21%	190	3.43%	232	1.23%	44
Wholesale	6.70%	408	4.59%	419	2.08%	36
Retail	9.09%	583	6.73%	525	3.67%	62
Business Service	13.06%	838	6.81%	603	2.49%	55
Utilities	5.02%	362	3.96%	312	2.62%	46
Mining	1.17%	85	1.14%	125	1.80%	44
Daily Rental	2.31%	143	0.38%	43	0.04%	4
Not in Use	2.98%	200	2.69%	257	2.06%	42
For Hire	4.97%	312	3.21%	271	3.93%	74
Other	0.00%	0	0.00%	0	0.00%	0
One-way Rental	0.57%	29	0.01%	1	0.00%	0
Personal Trans.	11.53%	575	3.73%	307	0.57%	9
Total	100.00%	6,430	100.00%	8,767	100.00%	1,996

Exhibit 4-24
National Diesel Vehicle Major Use by GVW Class

	8,500 - 14,000		14,001 - 33,000		Over 33,000	
Major Use	%	N	%	N	%	N
Agricultural	11.97%	142	8.50%	855	9.37%	4,900
Forestry	0.53%	17	1.00%	131	3.32%	2,193
Construction	8.72%	226	11.23%	1,316	15.82%	8,139
Contractor/Trades	8.30%	173	4.79%	430	1.82%	786
Manufacturing	4.96%	120	7.07%	665	7.51%	3,737
Wholesale	14.48%	428	18.61%	1,576	7.70%	4,225
Retail	14.15%	350	11.61%	1,037	4.38%	2,049
Business Service	16.74%	292	8.57%	825	5.20%	1,994
Utilities	4.27%	82	6.14%	423	1.14%	392
Mining	1.01%	23	1.42%	207	2.53%	1,380
Daily Rental	1.84%	60	4.71%	260	1.82%	935
Not in Use	2.39%	116	3.05%	492	0.69%	366
For Hire	6.36%	169	11.80%	1,418	38.62%	19,863
Other	0.00%	0	0.00%	0	0.00%	0
One-way Rental	0.95%	91	0.58%	95	0.04%	16
Personal Trans.	3.34%	53	0.92%	59	0.03%	21
Total	100.00%	2,342	100.00%	9,789	100.00%	50,996

A large proportion of heavy-heavy gas trucks are reported as being involved in agricultural use. About 24.41% of California trucks in this class were reported as being used for agriculture. Due to the small number of observations for the California sample of gas HHDT's, it may be more representative to look at national estimates for this class of vehicles. National data show 55.56% of gas HHDT's reporting agriculture as their major use.

For both gas and diesel trucks, lighter vehicle classes tend to show more use in the business services and contractor and trade categories. Heavier vehicle classes tend to show more use in the for-hire, agriculture and construction categories. The two largest use categories for diesel HHDT's in California were construction and for-hire. About 40.12% of California's diesel HHDT population reported their major use as for-hire transportation while 13.95% reported use in construction. National data show 38.62% for hire use and 15.82% construction use.

4.2.8 <u>Jurisdiction</u>

Until recently, for-hire vehicles faced an array of economic and rate regulation which did not impact on private carriers. Interstate for-hire carriers were regulated by the ICC while intrastate carriers often faced a variety of state regulations enforced by local public utility commissions. To determine the most common jurisdiction of operation TIUS asks three questions: "If this vehicle was for hire, what percent of the annual mileage was it operated interstate? Intrastate? Local?". TIUS data provides an additional variable which classifies all for hire vehicles according to their most common jurisdiction. A vehicle is classified as interstate, intrastate or local according to which one of these categories it operates most of its annual mileage in.

Exhibit 4-25 and Exhibit 4-26 shows gas and diesel truck population jurisdiction. Since there were a substantial number of records missing data in the jurisdiction field, California specific data for gas vehicles only contains 10 observations and is unreliable. The national gas HDT population shows a heavy concentration in local and intrastate jurisdiction categories. About 62% of gas HHDT's were operated primarily as intra-state vehicles while only 3.4% were operated as inter-state vehicles.

For heavy-heavy diesel vehicles, the population is concentrated much more heavily in the interstate category. National data show that approximately 69% of diesel HHDT's are operated predominantly as interstate vehicles. For California, the percentage of diesel HHDT's operating primarily as interstate vehicles is much lower, only about 38%

4.2.9 Operator Type

Exhibit 4-27 and 4-28 show that owner operators tend to comprise a greater percentage of the heavier vehicle classes. Data for the lower vehicle weight classes is sparse for California, but does seem to reflect national trends. The national LHDT gas and diesel populations are 92.79% and 87.21% motor carriers. The percentage of motor carriers falls and the percentage of owner operators increases in the heavier vehicle classes. Thus only 62.33% of gasoline HHDT's and 76.80% of diesel HHDT's are classified as motor carriers. Approximately 14% of diesel HHDT's operate predominately as independent owner operators at the national level.

Exhibit 4-25
California - Vehicle Jurisdiction by GVW Class

Vehicle Weight	Jurisdiction							
	Interstate		Intrastate		Local		Total	
	%	N	%	N	%	N	%	N
	Gasoline Vehicles							
8,500 - 14,000	50	2	50	2	0	0	100	4
14,001 - 33,000	39.69	1	51.48	2	8.82	2	100	5
Over 33,000	0	0	100	1	0	0	100	1
	Diesel Vehicles							
8,500 - 14,000	36.97	1	41.07	2	21.96	2	100	5
14,001 - 33,000	6.28	3	51.56	19	42.15	12	100	34
Over 33,000	38.6	129	43.96	175	17.43	76	100	380

Exhibit 4-26
National - Vehicle Jurisdiction by GVW Class

Vehicle Weight	Jurisdiction							
	Interstate		Intrastate		Local		Total	
	%	N	%	N	%	N	%	N
	Gasoline Vehicles							
8,500 - 14,000	16.12	32	36.17	99	47.72	121	100	252
14,001 - 33,000	15.35	35	38.70	101	45.96	111	100	247
Over 33,000	3.47	6	62.12	28	34.41	32	100	66
	Diesel Vehicles							
8,500 - 14,000	30.40	57	43.33	56	26.27	44	100	157
14,001 - 33,000	31.49	499	40.20	497	28.31	293	100	1289
Over 33,000	69.45	13655	22.71	3866	7.84	1179	100	18700

Exhibit 4-27
California - Vehicle Operator Type by GVW Class

Vehicle Weight	Operator Type							
	Motor Carrier		Independent		Leased		Total	
	%	N	%	N	%	N	%	N
	Gasoline Vehicles							
8,500 - 14,000	100	4	0	0	0	0	100	4
14,001 - 33,000	100	5	0	0	0	0	100	5
Over 33,000	100	1	0	0	0	0	100	1
	Diesel Vehicles							
8,500 - 14,000	89.02	4	10.98	1	0	0	100	5
14,001 - 33,000	94.19	31	5.81	5	0	0	100	36
Over 33,000	79.38	298	14.27	56	6.36	27	100	381

Exhibit 4-28
National - Vehicle Operator Type by GVW Class

Vehicle Weight	Operator Type							
	Motor Carrier		Independent		Leased		Total	
	%	N	%	N	%	N	%	N
	Gasoline Vehicles							
8,500 - 14,000	92.79	220	7.02	24	0.2	2	100	246
14,001 - 33,000	78.71	189	18.97	51	2.32	6	100	246
Over 33,000	62.33	38	20.4	17	17.27	6	100	61
	Diesel Vehicles							
8,500 - 14,000	87.21	131	10.27	23	2.52	2	100	156
14,001 - 33,000	83.65	1062	12.52	172	3.83	67	100	1301
Over 33,000	76.8	14446	11.11	2288	12.09	2262	100	18996

5 DATA COLLECTED FROM INSTRUMENTED HEAVY-DUTY TRUCKS

The purpose of this task was to collect data on actual usage patterns of heavy-duty trucks (HDTs) using on-board data loggers. Actual usage data would provide information about speed distributions, average speeds, number of daily trips, average trip length, idle time, and number of starts for development of emission rates in the EMFAC vehicle emissions model. The current model uses a single speed distribution for all HDTs which does not take into account differences in usage based on truck weight, fuel type, and area of operation (local, short haul, or long haul). In addition, the speed distributions used in the model are based on light duty vehicle speed profiles. ARB plans to update this data on a larger number of trucks so that variations by truck type and usage could be determined.

The ARB was also interested in examining the possibility of developing new emission test cycles for HDTs that take into account the actual variations in usage by weight class, fuel type, and area of operation. In this contract, the ARB required that a limited set of detailed usage data be collected for developing speed traces and load profiles that could be used to establish these new emission test cycles.

In order to accomplish these objectives, JFA was asked to instrument vehicles with on-board data loggers capable of collecting two kinds of data. The first data set, referred as speed bin data, was designed to look at speed and usage over a relatively long period of time. The data record information on each trip that the vehicle makes over an eight day period. These data include the trip start and end time, the mileage traveled during the trip, the average speed, the amount of idle time, and the distribution of speeds recorded in 5 mph increments. The second set of data, referred as the second-by-second data, was designed to provide detailed usage data over a relatively short period of time. This data set was consisted of road speed, engine speed, load, and road gradient information on a second-by-second basis for a 24-hour period.

The remainder of this chapter describes this data collection process and summarizes some of the data that were collected. The types of data collected and the instrumentation used is first described. Next, the approach to sampling the fleet and procuring vehicles is described. This is followed by a brief section describing methodological problems and problems encountered in the field which are important to understanding the data. Finally, summary statistics from the speed bin data are presented as required by the contract. The second-by-second data were provided to ARB directly in raw form and are being used by ARB to develop speed traces for emission test cycle development. The contract did not require any further analysis by JFA.

5.1 TYPES OF DATA AND INSTRUMENTATION

5.1.1 Speed Bin Data

The record structure of the speed bin data base is presented in Exhibit 5-1. Each record in the speed bin data base represents a vehicle trip. The record is triggered when the engine is turned on. The data logger records the time and date of each engine-on and each engine-off event and this identifies a unique trip (called a trip-leg in the data base). For each trip the data logger records the average speed (a derived data element calculated by dividing the total mileage of the trip by the total time - trip end time minus trip start time). The data logger also records the trip length in miles and the number of seconds at idle. Idle is defined as a condition in which the data logger is receiving a tachometer signal (the indicator of engine activity) and no speedometer signal.

Road speed is sampled by the data logger every second and the result is stored in a speed bin. The data record shows the number of seconds spent in each speed bin and the time spent at idle for the entire trip. There are 16 speed bins, each representing a 5 mph increment (>0-5 mph, >5 mph-10 mph, etc., with the last bin representing speeds greater than 75 mph).

The speed bin data were collected for a period of at least eight consecutive days on each vehicle. In many cases, this period included days on which the vehicle was not operated, either because it was out of service or because it was not a normal business day for the fleet in question. In some cases the speed bin data were collected for more than eight consecutive days. This usually occurred when it was difficult to schedule data extraction with the fleet manager for the eighth day of the test. In these cases, adjustments were made in the data analysis so that these vehicles would not bias the summary statistics.

5.1.2 Second-by-Second Data

The record structure of the second-by-second data base is shown in Exhibit 5-2. Each record in the second-by-second data base represents a second of operation. In order to economize on storage space in the data logger, data were only recorded for seconds in which the engine was operating. This was determined by the data logger if it was receiving either a speedometer or a tachometer signal. An internal clock kept track of the time measured in seconds offset from the initialization of the data logger. Thus, it is possible to determine periods during the test in which the vehicle was not operating.

Each record in the second-by-second data base provides the instantaneous road speed (mph) and engine speed (rpm). The ARB also desired load indicators to explain anomalies in the speed and tachometer traces obtained from the second-by-second data. The original plan was to provide a measure of throttle (or rack) position as a percent of wide open conditions. This proved problematic to implement. An alternative, accelerator pedal position, was rejected for driver safety reasons. The final decision was to measure

Exhibit 5-1
Record Structure of the Speed bin Data Base

Structure of Data Base File: **TRIPLEGS.DBF**

Purpose : One record for each engine on/off cycle. These records are only recorded for long horizon units (no CSM3).

Field	Type	Num	Dec	Description
EXTNUM	Character	4		Extraction No. 0001-9999
ENGINE_ON	Character	14		YYYYMMDDhhmmss Engine On
ENGINE_OFF	Character	14		YYYYMMDDhhmmss Engine Off
AVE_MPH	Numeric	2		Average trip speed, in mph
MILES	Numeric	8	3	Distance of trip, in miles
IDLE_SECS	Numeric	6		Engine Idling time, in sec.
BIN1	Numeric	8		Seconds driving at 0 - 5 mph
BIN2	Numeric	8		Seconds driving at 5 - 10 mph
BIN3	Numeric	8		Seconds driving at 10 - 15 mph
BIN4	Numeric	8		Seconds driving at 15 - 20 mph
BIN5	Numeric	8		Seconds driving at 20 - 25 mph
BIN6	Numeric	8		Seconds driving at 25 - 30 mph
BIN7	Numeric	8		Seconds driving at 30 - 35 mph
BIN8	Numeric	8		Seconds driving at 35 - 40 mph
BIN9	Numeric	8		Seconds driving at 40 - 45 mph
BIN10	Numeric	8		Seconds driving at 45 - 50 mph
BIN11	Numeric	8		Seconds driving at 50 - 55 mph
BIN12	Numeric	8		Seconds driving at 55 - 60 mph
BIN13	Numeric	8		Seconds driving at 60 - 65 mph
BIN14	Numeric	8		Seconds driving at 65 - 70 mph
BIN15	Numeric	8		Seconds driving at 70 - 75 mph
BIN16	Numeric	8		Seconds driving at 75+ mph

Total Record Size: 177 Fields: 22

Exhibit 5-2
Record Structure of the Second-by-Second Data Base

Structure of Data Base File: **SECBYSEC.DBF**

Purpose: One record for each second of Engine On time or Driving time. These records are only recorded for short horizon units (equipped with CMS3)

Field	Type	Num	Dec	Description
EXTNUM	Character	4		Extraction N0. 0001 - 9999
SEC_OFFSET	Numeric	6		Secs offset from SHORT_BEG in the related EXTRACTS record.
MPH	Numeric	2		Road Speed, in mph.
RPM	Numeric	4		Engine Speed, in rpm
MNFLD_PRES	Numeric	5	2	Manifold Pres. 0-99.99 psi
GRADIENT	Numeric	3		Road Gradient -99° to +99°
Total Record:	25			Fields: 6

intake manifold pressure. This is an excellent load indicator for gasoline (Otto cycle) engines but is more ambiguous for diesel engines. Intake manifold pressure in a diesel engine measured before the turbo-charger does measure a vacuum created by the air draw across the air filter. The magnitude of this vacuum is very small and varies with the level of restriction created by the air filter. According to manufacturers we spoke with during the development of this instrumentation, there is sufficient variation in pressure with load (and rpm) to provide a reasonable load indicator. Actual pressure was measured (which varies by vehicle relative to load) and ARB is using this as an indicator of load variations rather than as a measurement of actual engine load.

The final data element in the second-by-second data set is a measurement of road gradient. This is actually a measurement of vehicle (cab) gradient relative to a reference assumed to be level. This measurement was also taken as a load indicator.

5.1.3 Vehicle Reference Data

In addition to the data collected automatically by the on-board data logger, a data set was collected manually to identify each vehicle. The following data elements were collected:

- Vehicle ID (assigned by JFA)
- Fleet name
- Beginning and ending odometer reading
- Vehicle Make
- Vehicle Model
- Vehicle Model Year
- License Plate Number
- VIN
- Engine Make and Model
- Engine Size
- Engine Age
- Fuel Injected or Carburatted Engine
- Fuel Type
- Tire Size
- Area of Operation (local, short haul, or long haul - identified by the fleet manager)
- Functional Usage Type
- GVWR
- Number of Engine Rebuilds
- Annual Mileage Traveled (if known)
- Percentage of Total Miles Traveled Out-of-State (if known)
- Percentage of Total Miles Traveled on Freeways (if known)
- Average Vehicle Weight During Test (estimated by fleet manager, if known).

Vehicle data sheets were filled out for each instrumented truck which included the above information.

The Vehicle IDs were provided by JFA to uniquely identify the vehicles and to facilitate sorting of the data collected for analysis purposes. A four character ID field was provided with the following significance:

- the first digit determines fuel type (0 = gasoline, 1 = diesel)
- the second digit determines vehicle weight class (1 = light-heavy, 2 = medium-heavy, 3 = heavy-heavy, and 4 = super heavy)
- the third digit determines area of operation (1 = local, 2 = short haul, 3 = long haul)
- the fourth digit determines which vehicle in the cell the truck represents.

5.1.4 Instrumentation

Data collection for the project used a standard fleet monitoring system as the basic data logger. The unit is manufactured by Argo Instruments and is used throughout the transportation industry for routine fleet management applications. Six data loggers were used in the study, two of which included upgraded RAM chips in order to facilitate the expanded memory requirements of second-by-second data recording. Argo developed custom firmware and data acquisition software for the project. In addition, intake manifold and road gradient measurement devices were developed for the project by Mobility Systems and Equipment (MSE). The intake manifold pressure measurement transducer was equipped with three different calibration settings to account for the wide range of vacuum readings encountered in gasoline and diesel trucks. The pressure transducer was a differential pressure sensor referenced to ambient pressure in order to eliminate the effect of altitude change in the measurement. The road gradient measurement device used both a quartz rate sensor gyro device of the type used in aircraft navigation and a mass pendulum inclinometer. The quartz rate sensor provided the most effective method of eliminating the effects of acceleration/deceleration in the measurement and the mass pendulum inclinometer was used to periodically re-reference the zero-slope point. The road gradient measurement device also included a low-pass filter for eliminating the effect of road bumps. A more detailed description of the instrumentation is included in Appendix 7.

5.2 SAMPLING AND VEHICLE PROCUREMENT

5.2.1 Sampling Approach

ARB established a number of requirements and constraints for the test program that had to be satisfied in the sample selection. A minimum of 40 vehicles were to be tested for speed bin data and a minimum of 10 vehicles were to be tested for second-by-second data. It was JFA's belief, that even under the best of circumstances, the 40 vehicle sample size for the speed bin data was too small to yield statistically significant results. Yet this sample could provide sufficient data to assist in evaluating assumptions that are necessary in running the emission inventory models and would greatly expand the data base on vehicle usage.

The vehicles selected for testing were supposed to be as representative as possible of the in-use vehicle fleet. In order to ensure this representative sample, JFA decided that systematic stratification was appropriate in sample selection. There are a number of variables that were believed to be correlated with variations in operating patterns that could be used as stratification variables. Given the small number of vehicles that were to be tested, it was important to keep the number of strata relatively small in order to avoid too few vehicles in any one cell. JFA selected weight, fuel type, and area of operation as the three stratification variables. Four weight classes were selected, roughly corresponding to ARB's weight classification scheme in EMFAC. The following categories were used:

- Light-heavy (8500 to 14,000 LB GVW)
- Medium-heavy (14,001 - 33,000 lb GVW)
- Heavy-heavy A (33,000 - 60,000 lb GVW)
- Heavy-heavy B (60,000+ lb GVW) also called super-heavy.

The fourth weight category was included because JFA believed that heavier Class 8 trucks (including semi-trailers, tractor-trailers, and double-trailers) might have different usage characteristics that were correlated with weight that might not be adequately represented in the sample if this were not accounted for in the stratification scheme. One objective of the analysis was to determine if this assumption was correct and if development of a super-heavy weight class in EMFAC makes sense for the future.

Two fuel types were selected (gasoline and diesel) and three areas of operation. The three areas of operation were defined as follows:

- Local (most VMT within 50 miles of home base)
- Short haul (most VMT within 50-200 miles of home base)
- Long haul (most VMT over 200+ miles from home base).

In all, there were a total of 24 possible strata (cells). In fact, many of these cells were eliminated because insufficient population/VMT occurred in these cells (e.g., long-haul gasoline super heavy).

Several approaches to sample weighting by strata were considered. First, it was observed that if the sample weights were based on expected within strata variation (with more variable strata being sampled more extensively) it might be very difficult from known information to predict how each strata should be weighted. Logical alternatives were to use either percent of VMT or percent of population to weight the sample. Distributions for both variables for California are available from TIUS, although in some cases, statistical significance of the data is questionable. ARB believed that strata representing the higher percentage of VMT should be sampled at a greater rate based on likely correlation between VMT and overall emissions. The sample weights were multiplied by the total sample size and rounded to give a first estimate of the sampling plan. Immediately, certain cells were dropped from consideration because they had an inadequate share of VMT. ARB and JFA agreed that no cell that was included in the sample should have less than 2 vehicles and in order to accommodate this, no cell should have more than 5 vehicles. With these constraints the sampling plan was adjusted to that which is presented in the first column in Exhibit 5-3.

It should be noted that two of the cells that were included in the original sampling plan were very difficult to identify. These included light-heavy diesel long haul and medium-heavy gasoline long haul. A review of the California TIUS data showed that while these cells accounted for enough VMT to be included in the sampling plan, these estimates of VMT were based on a very small number of observations. At the national level, these two cells also represent a very small percent of total VMT and based on these national percentages, would not have been included in the sampling plan. Based on these observations, these two cells were ultimately dropped from the sampling plan and the four trucks originally allocated to these cells were distributed to other cells based on percent of VMT.

The decision to revise the sampling matrix described in the previous paragraph was made at a point in the test program after roughly half of the vehicles had been tested. At that point in the program it had become clear that in some cases, actual collected data showed truck area of operations that were different than the area of operation identified by the fleet manager (for example, the fleet manager might classify a truck as a local truck but actual data showed that the truck regularly made trips over 100 miles distance).[8] JFA re-classified these trucks based on their actual driving behavior and re-balanced the sampling matrix to ensure that cells with high VMT percentages were still highly sampled and that no cells included less than 2 trucks (the prohibition against more than 5 trucks in a cell was dropped at this point). The revised sampling matrix is presented in the second column in Exhibit 5-3.

Since participation in the data collection program was strictly voluntary, JFA found it extremely difficult to get willing participants in every test cell who were able to schedule data collection within the time constraints of this project. At the conclusion of the project some test cells did not include enough trucks to meet the requirements of the revised sampling plan. In addition, owner mis-classification of trucks by both area of operation and weight continued to occur throughout the program which left some cells with too few trucks and other cells with more than enough trucks. The final distribution of the sample that was instrumented for speed-bin data is presented in the third column of Exhibit 5-3. It should be noted that additional data collection efforts are underway to ensure coverage

[8]The issue of mis-classification of trucks' area of operation is described in more detail in Section 5.3 Data Collection Issues.

of each test cell to at least the level required by the revised sampling plan. These additional data will be provided to ARB after the conclusion of the contract for use in future analyses.

Exhibit 5.3
Sampling Plan

VEHICLE TYPE	ORIGINAL SAMPLE	REVISED SAMPLE	VEHICLES COMPLETED & IN REPORT
Light heavy gasoline local	2	3	2
Light heavy gasoline short	2	2	2
Light heavy diesel local	2	2	1
Light heavy diesel short	2	2	2
Light heavy diesel long	2	0	0
Medium heavy gasoline local	2	2	3
Medium heavy gasoline long	2	0	0
Medium heavy diesel local	2	4	4
Medium heavy diesel short	2	2	5
Heavy heavy diesel local	3	3	2
Heavy heavy diesel short	3	3	2
Heavy heavy diesel long	3	3	1
Super heavy diesel local	3	3	2
Super heavy diesel short	5	8	6
Super heavy diesel long	5	6	0

The 10 trucks to be instrumented for second-by-second measurements were selected to provide one per cell covering the 10 cells with the largest percent of VMT. Towards the end of the project, JFA agreed to do as many additional second-by-second tests as time and budget would permit, measuring only road speed and engine speed. The cells for which second-by-second measurements were completed were:

- Light-heavy gasoline local
- Light-heavy diesel local

- Medium-heavy gasoline local
- Medium-heavy diesel local
- Medium-heavy diesel short haul
- Heavy-heavy diesel local
- Heavy-heavy diesel long haul
- Super-heavy diesel short haul

5.2.2 Vehicle Procurement

One of the first challenges in procuring vehicles for the test program was identifying fleets. ARB had established a requirement that no more than three vehicles could be procured from any one fleet. Therefore, a minimum of 14 fleets needed to be identified. In order to identify fleets for the test program JFA used several data bases of trucks in California. JFA's preferred sampling frame would have been a sorted list of addresses of truck owners obtained from the DMV registration files. Unfortunately, information at this level of detail is considered confidential by DMV and repeated attempts to get this information were unsuccessful.

The first data base used by JFA was the USDOT/FHWA Motor Carrier Census (MCMIS) file. This file includes a listing of all fleets required to register with the Federal Highway Administration either because they have interstate operating authority or because they have hazardous material operating authority. In August of 1994, JFA used the April 1994 file to extract a list of 20,050 California carriers. From this list, a random (8.33%) sample of active carriers was selected as a starting point. In addition to name, address, and phone number information, the file also indicated the number of power units operated by the fleet. JFA contacted those carriers with at least three power units.

Since the MCMIS file had mostly interstate carriers, the carriers identified through the list tended to have the larger long haul trucks (although some other categories were identified). In order to broaden the coverage of truck owners JFA tried using files of regulated intrastate carriers from the California PUC. These files, which were somewhat dated, included lists of all for-hire fleets that required PUC operating permits. This data base had a very high percentage of disconnected phone numbers and the typical trucks identified also tended to be higher weight vehicles.

Based on the experiences with these two data files, JFA reasoned that many of the lighter weight vehicles, which included a high percentage of delivery and service vehicles, would be owned by private fleets. JFA purchased from TTS Industries, their California private fleet directory, which contains over 1100 records of private fleets located in California. TTS admits that this directory is not a complete listing of private fleets but they believe the directory includes at least the largest one-third of fleets. The directory identifies a fleet contact, address and phone number, the number of trucks, tractors, and trailers owned, whether or not the fleet includes trucks in each of several weight classes, and the primary business of the fleet owner. This list proved to be one of the most successful methods of identifying participants in the program.

When JFA reported difficulty identifying fleets with lighter weight trucks, ARB suggested that some government fleets that might have this type of truck could be included in the sample. Local government fleets expressed a high willingness to participate in the program and JFA and ARB agreed to limit their participation to fill-ins when private fleets could not be identified. One government fleet (two vehicles) was included in the data reported herein and a second fleet (one vehicle) will be provided to ARB after the contract is completed.

JFA also contacted the California Trucking Association (CTA) for help identifying potential participants in the program. CTA provided an endorsement of the program and agreed to spread the word among their membership that they believed it would be beneficial to the industry for members to participate. This helped convince several fleets to participate in the program. In addition, CTA provided the names of several fleets they believed would participate. Of these, some were still hesitant to participate and others only had heavier weight trucks for which JFA had good coverage.

The last source of names of fleets used by JFA were personal contacts of Baytech Corporation, a JFA subcontractor. Baytech manufactures and installs natural gas conversion equipment that is targeted for the medium and heavy duty truck market. Baytech was able to identify six fleets that were willing to participate in the program.

The general approach to vehicle procurement was to contact the fleet by telephone and identify the fleet manager, transportation manager, or other appropriate decision-maker. The program was explained briefly over the phone and an information packet was faxed to the manager if he/she was willing to consider participation. The information package included a fact sheet that explained the purpose of the project, the measurements that would be taken, and how the data would be used. The fact sheet promised that data collected in the program would not be used for any regulatory enforcement actions nor would any confidential data be disclosed. The fact sheet explained the primary benefits of the program to the participant as the availability of operating data that many companies install their own fleet monitors to receive and that accurate data would ensure that regulatory programs in the future would be reasonable and unbiased. The fact sheet also indicated that CTA supported participation in the program.

After the fax had been sent, a follow-up phone call was made to the manager. If the manager was willing to participate, a vehicle classification matrix was sent to the fleet for the manager to indicate the number of vehicles available in each cell. In addition, a more detailed letter describing the instrumentation and installation procedures was sent to the fleet.

Technicians from Baytech and KARCO Engineering (another JFA subcontractor) were responsible for scheduling the installation of equipment. When the appointment was made, the technician reviewed the installation procedure with the manager, requested certain technical information in advance, and confirmed the types of vehicles that would be tested. This was re-confirmed at the installation site. The instruction packet provided to the technicians is included as Appendix 8 to this report. Copies of the FMS 1332 installation guide and the DAS Users Manual were provided to ARB under separate cover. A typical installation took approximately 2 hours per vehicle.

5.3 DATA COLLECTION ISSUES

The data collected for this project represents one of the first systematic attempts to characterize truck driving patterns based on actual in-use monitoring for emission modeling purposes. While these data are revealing of many characteristic usage patterns that can aid in improvement of the existing emission models, there are a number of issues that came up during the project that should be understood in order to not misinterpret the data. Generally, these issues fall into two main categories: sampling issues and data collection technology issues. Each of these is discussed below.

5.3.1 Sampling Issues

The ability to obtain good representative samples of the California HDT population for inclusion in the instrumented truck data collection program proved to be one of the greatest challenges facing this research project. As noted previously, a pre-stratified sampling approach was used to ensure representativeness of the sample. Stratification variables were selected based on three criteria: 1) their ability to explain variation in driving behaviors, 2) the ability to identify the extent of the population that actually fit into each stratum, and 3) the need to keep the number of strata small because of the limited number of trucks that could be included in the sample. The three stratification variables (weight, fuel type, and area of operation) appeared *a priori* to satisfy these criteria. However, after reviewing the data, it is apparent that variations in usage are not always sufficiently captured by these stratification variables.

A good example of this problem is found in the case of local driving. During the study, we found several very distinct types of local driving. One type of local driving, exemplified by parcel pickup and delivery trucks, is characterized by an extremely large number of daily trips of very short duration at low average speeds. Another type of local driving, exemplified by certain wholesale to retail delivery vehicles, involves a smaller number of trips which are far enough apart that they include a substantial amount of freeway driving. A third type of local driving, exemplified by certain construction trucks and service vehicles, involves only two or three trips per day to a job site and additional starts and idling time which may be associated with movement around a job site or the operation of auxiliary equipment. Since these driving behaviors are not well correlated with weight or fuel type, there was no way, given the sampling plan, to ensure proper representation of these driving modes in the data. It appears that stratification by usage categories is critical in order to properly represent the wide range of established truck driving patterns but this will require instrumentation for much larger samples than were possible in this study. The usage of trucks included in the study is presented in Exhibit 5-4.

A second data collection issue associated with how the sample was stratified has to do with the usefulness of the area of operation variable for stratification. Area of operation did prove to be a useful stratification variable in that it distinguished certain usages that are clearly correlated with distinctive driving behaviors. In addition, the TIUS data made it possible to determine what percent of VMT was associated with different areas of operation. Nonetheless, the use of area of operation as a stratification variable had several shortcomings. One problem was that fleet managers would sometimes mis-classify their own trucks. When the sample was selected, JFA contacted the fleet and asked the point of contact to report the number of trucks they could offer for testing in each cell of the sampling matrix. The selection of specific trucks for inclusion in the sample was thus determined based on the point of contact's perception of how the trucks were typically driven. When data were collected, in some cases, actual driving behavior seemed different than the classification by the point of contact would suggest. In 15% of the data collected, trucks were re-classified as to area of operation after reviewing the data.[9] It is not clear whether this mis-classification problem occurred because fleet managers have different perceptions as to what is meant by local, short haul, and long haul driving, whether the actual area of operation of a given truck is highly variable, or whether, the point of contact simply did not know how the truck was typically used (the least likely case).

A related problem was the selection of cut-points for separating the three areas of operation (local, short haul, and long haul). Sometimes, these cut-points did not match the perception of the fleet manager as to the type of driving their trucks were engaged in. To some extent this may have been because the cut-points did not correspond to any standard industry definition. In addition, perceptions of what is short haul vs. what is long haul may vary depending on the usage of the truck. For some usages, daily trips of 150-200 miles may be considered long haul, while they are clearly not considered to be long haul by line-haul interstate carriers. These definitional problems may have had an impact on more than just the mis-classification of trucks by their owners for sampling purposes. It is possible that had a different definition of local, short haul, and long haul been used, a different distribution of driving behaviors and usage might have been achieved.

Another problem associated with area of operation definitions is that some types of trucks appear to have highly variable areas of operation on a day-to-day basis. This may be characteristic of their usage and this further argues for a usage-based stratification scheme rather than one based on area of operation.

Probably the most significant sampling issue in terms of its impact on results is associated with non-response and self-selection bias in the sample. As noted above, participation in the data collection program was strictly voluntary. There are a number of

[9]An additional 6% of trucks in the sample of data collected (2 trucks) were re-classified because they were the wrong GVW class. In one case this occurred because the truck owner confused GVW with unladen weight and in the second case their was a miscommunication with the installation technician as to which truck was to be instrumented.

Exhibit 5-4
Truck Usage

VEHICLE TYPE	VEHICLE ID NUMBER	USAGE
Light heavy gasoline local	1) 0112 2) 0113	1) Wholesale to retail bakery delivery truck 2) Parcel pick-up & delivery truck
Light heavy gasoline short	1) 0121 2) 0122	1) Utility field service vehicle 2) Beverage delivery truck
Light heavy diesel local	1) 1112	1) Shop errand truck
Light heavy diesel short	1) 1121 2) 1122	1) Beverage delivery truck 2) Beverage delivery truck
Medium heavy gasoline local	1) 0114 2) 0211 3) 0212	1) Fence supply truck 2) Parcel pick-up & delivery truck 3) Parcel pick-up & delivery truck
Medium heavy diesel local	1) 1211 2) 1221 3) 1223 4) 1215	1) Ice delivery truck 2) Ice delivery truck 3) Ice delivery truck 4) Street sweeper
Medium heavy diesel short	1) 1224 2) 1229 3) 1321 4) 1322 5) 1323	1) Hauls general freight 2) Hauls general freight 3) Food service delivery truck 4) Food service delivery truck 5) Food service delivery truck
Heavy heavy diesel local	1) 1312 2) 1313	1) Bulk delivery vehicle 2) Bulk delivery vehicle
Heavy heavy diesel short	1) 1425 2) 1661	1) Feed mill delivery truck 2) Garbage Truck
Heavy heavy diesel long	1) 1331	1) Bulk delivery vehicle
Super heavy diesel local	1) 1412 2) 1413	1) Ready-mix cement truck 2) Aggregate hauling truck
Super heavy diesel short	1) 1421 2) 1422 3) 1431 4) 1424 5) 1432 6) 1423	1) Baked goods distribution truck 2) Baked goods distribution truck 3) Baked goods distribution truck 4) Feed mill delivery truck 5) Feed mill delivery truck 6) Building supply delivery truck

reasons why collecting data from trucks in this type of program is more difficult than it is when similar approaches are used to collect data from light duty vehicles. Trucks are used in commercial enterprises and taking trucks out of service for even a few hours to install on-board data collection equipment is more than an inconvenience for the operator. JFA tried to make accommodations by doing installation work at night or on weekends, but if there were no personnel available at the site during off-hours, this was impractical. JFA investigated the extent to which monetary compensation in the range of $500- $1000 per fleet would affect decisions to participate in the program and we found that this generally did not affect decisions. In addition, aside from the normal level of distrust of government that is prevalent in many industries today, several extremely contentious regulatory issues have made relationships between the ARB and the trucking industry particularly difficult at this time.

As a result, there were certain cells in the sampling matrix for which adequate representation could not be achieved within the time constraints of the project and this leads to the potential for non-response bias in the results. In addition, since it was difficult to recruit participants and the number of participants in each cell is typically small (often 2-3 trucks per cell), bias can be introduced based on how representative those trucks that did agree to participate might be of the cell that they represent.

5.3.2 Technology Issues

In general, the data collection equipment functioned well in the field and there were few significant equipment breakdowns. There were, however several field technical problems that are worth noting. During the summer of 1996 there were significant instances of data loss from tests that were traced to an incompatibility between the Windows 95 operating system on laptop computers used for data extraction and the on-board computer. Subsequently, data collection technicians were instructed to always shutdown Windows completely (rather than "shortcutting" to DOS) prior to using the data acquisition system software. After this adjustment to standard operating procedures was made, no further data loss was encountered.

Another common field problem was poor connections to ignition power. In order to conserve power, the on-board computer goes into a "sleep" mode when the vehicle is not operated. When the ignition switch is turned on, this provides a signal for the unit to "wake-up." In a number of cases, intermittent connections to ignition power caused loss of data because no "wake-up" signal was received by the on-board computer. This was not detected during check-out of the instrumentation when the units were installed since power is provided to the on-board computer when it is connected to a laptop PC during setup. Thus, the on-board computer never entered its "sleep" mode during the installation and checkout procedure.

There were also several cases of tampering that resulted in data losses. The most prevalent problem occurred when a truck was brought in for service and the service technician disconnected the on-board computer during maintenance procedures. Frequently, the service technicians would try to re-connect the computers before the vehicles were placed back in service but often the re-connection was done improperly causing data loss. In only a few isolated cases did it appear that drivers had disconnected the data collection equipment. JFA was concerned that this problem might be more prevalent since the data collection equipment could be used by the fleet manager to monitor excessive speeding or falsification of driver logs. In all cases, JFA recommended to the fleet managers that they inform their drivers as to the purpose of the test and how the data would be used so as not to arouse suspicion and this was generally effective.

Several technical problems were encountered with the manifold pressure measurement device. Although the calibration settings were developed based on technical data provided by diesel engine manufacturers, JFA found that intake vacuum in diesel engines was highly variable from truck to truck and was frequently too small to detect load variations over the operating range of the truck even on the most sensitive calibration setting. This resulted in most of the second-by-second tests on diesel trucks being unsuccessful in attempts to collect load information. However, some diesel tests were successful and all tests on gasoline trucks were successful.

5.4 DATA ANALYSIS

Prior to conducting the analysis some data preparation was undertaken. The first trip taken on the first day of the data logger operation was discarded from the data base assuming that the trip may have been taken to test the proper operation of the data logger. One truck exhibited very unusual driving behavior. This truck seemed to have the engine turned on and off for very short periods of time frequently during the day without driving at all or any appreciable distance. This truck was a construction-related vehicle and this particular driving behavior was difficult to explain. The data from this truck were discarded. In another case, consecutive short trips of 0.001 miles or less were eliminated and determined to be insignificant from an emissions perspective.

5.4.1 Speed Profiles

The highest percent of idle time is exhibited by light-heavy-duty diesel trucks (38.90%) followed by heavy-heavy-duty diesel trucks (37.66%), medium-heavy-duty diesel trucks (24.91%), light-heavy-duty gasoline trucks (20.24%), medium-heavy-duty gasoline trucks (19.27%) and super-heavy-heavy-duty trucks (15.25%). Some bias in the results was noticed that should be explained. The most significant of these biases is with respect to the under-representation of long haul trucks in the sample. The sampling plan for diesel heavy-heavy long haul trucks called for 3 trucks in the sample and only one was included. If this truck is representative of diesel heavy-heavy long haul driving, under-representation of this truck type would have had the effect of increasing the percentage of idle time for the heavy-heavy weight class (the one heavy-heavy long haul truck had spent only 15.25% of its driving time at idle).

Light-heavy-duty gasoline trucks exhibit the highest fraction of low speed (0-30 mph) driving (36.05%) followed by medium-heavy-duty diesel trucks (28.73%), light-heavy-duty diesel (27.36%), heavy-heavy-duty diesel trucks (5.59%), and super-heavy-duty diesel trucks (3.1%). In this case, the under-representation of long haul trucks would tend to further skew these results.

The highest fraction in high speed driving (over 50 mph) is exhibited by super-heavy-heavy-duty diesel trucks (34.67%) followed by medium-heavy-duty diesel trucks (32.56%), light-heavy-duty gasoline trucks (31.78%), heavy-heavy-duty diesel trucks (21.04%), medium-heavy-duty gasoline (18.26%) and light-heavy-duty diesel trucks (17.16%).

Exhibits 5-5a through 5-5g show the percent of time spent at different speed bins during a trip - by weight class/fuel type.

Fig. 5-1a
All Vehicles Speed Profile

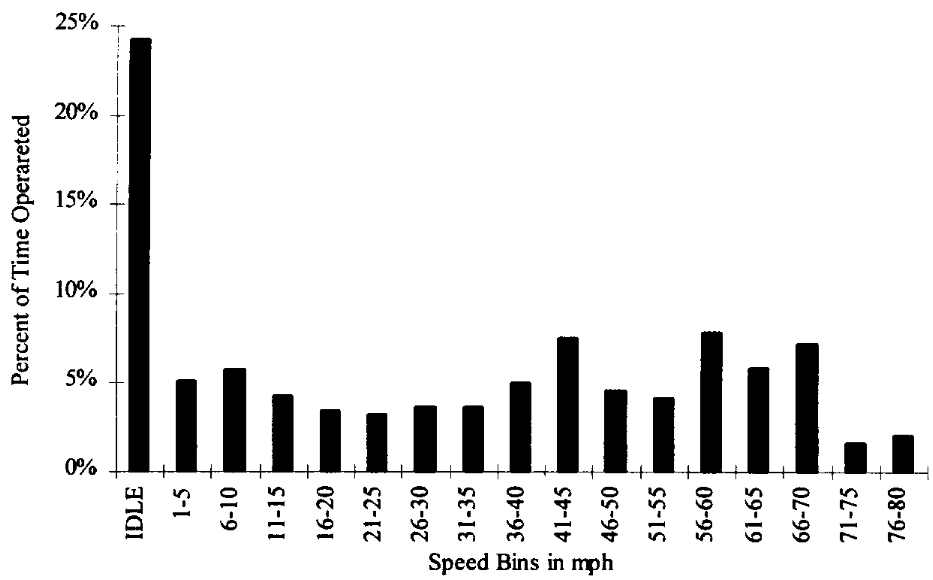


Fig. 5-1b
SHHDD Vehicles Speed Profile

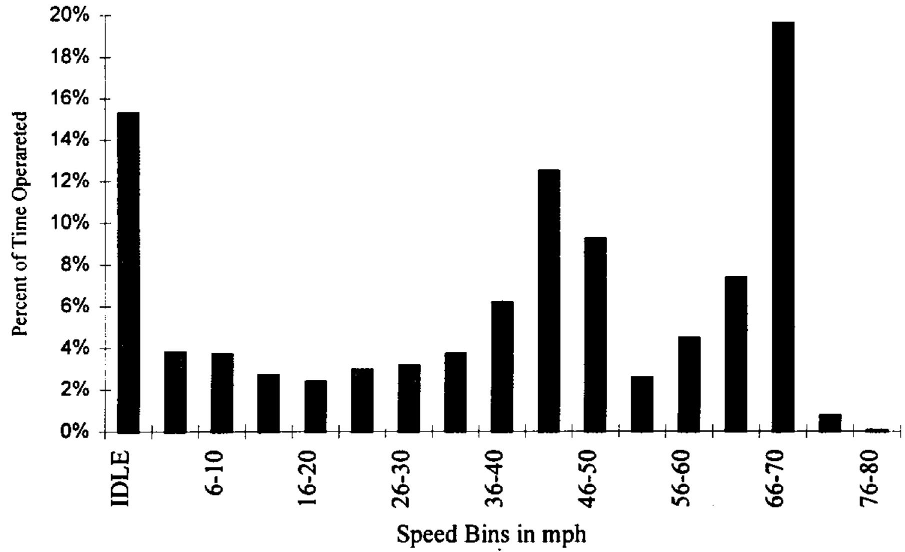


Fig. 5-1c
HHDD Vehicles Speed Profile

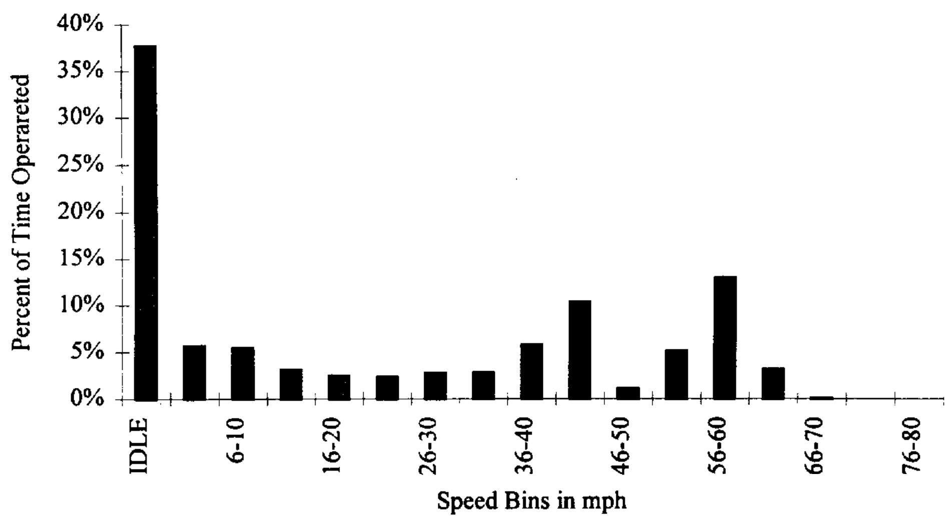


Fig. 5-1d
MHDD Vehicles Speed Profile

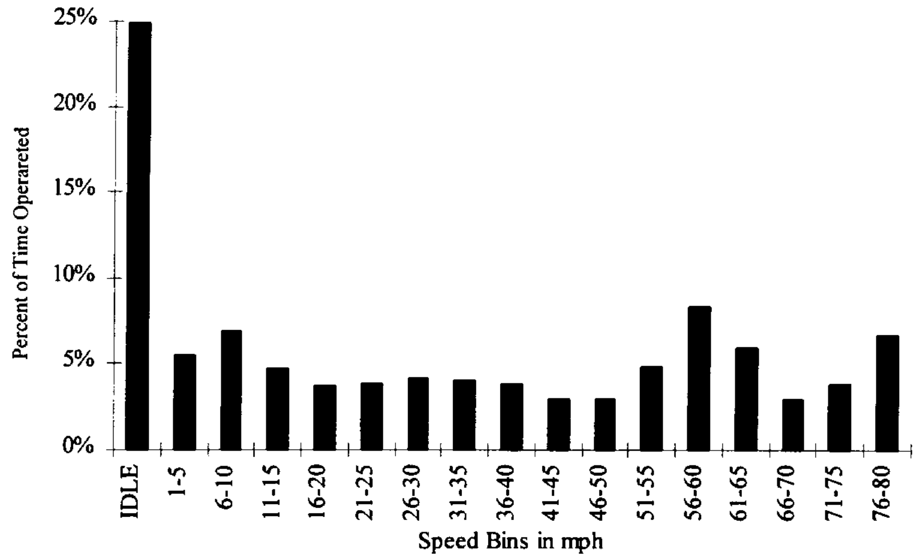


Fig. 5-1e
MHDG Vehicles Speed Profile

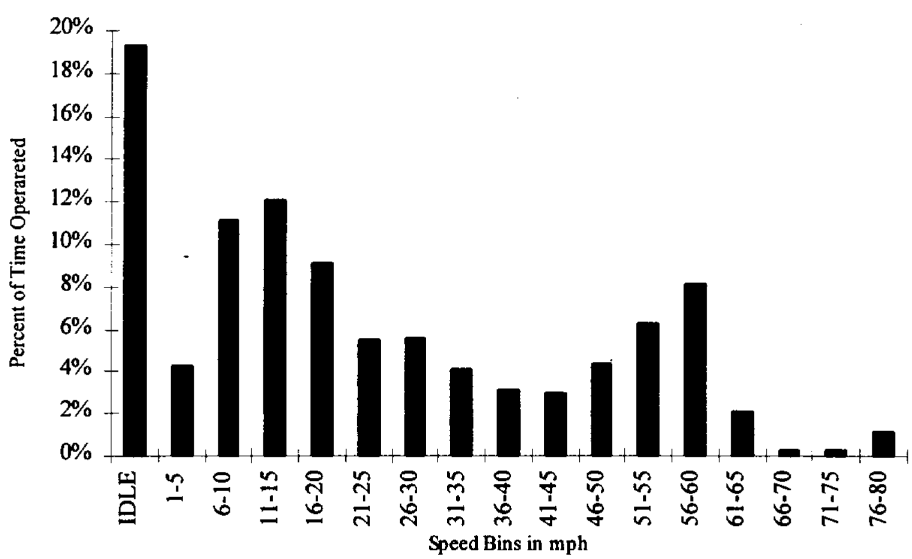


Fig. 5-1f
LHDD Vehicles Speed Profile

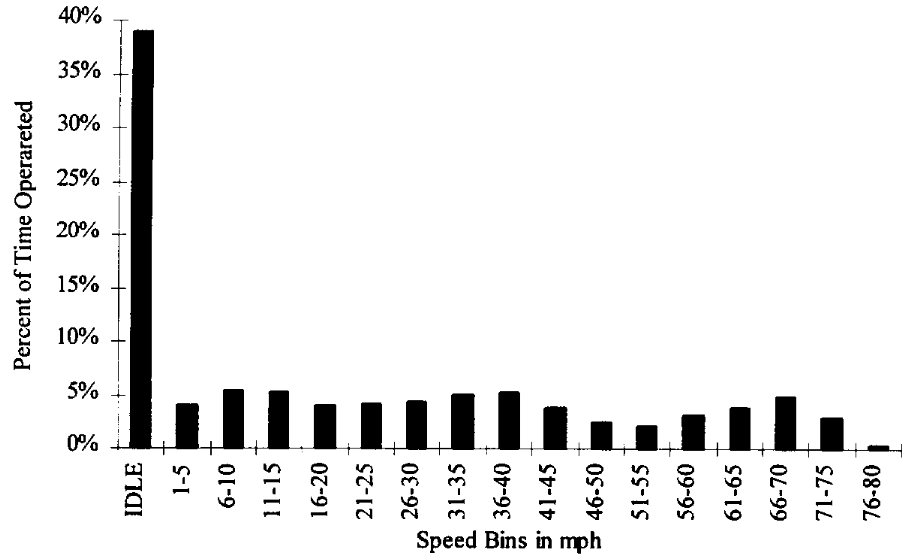
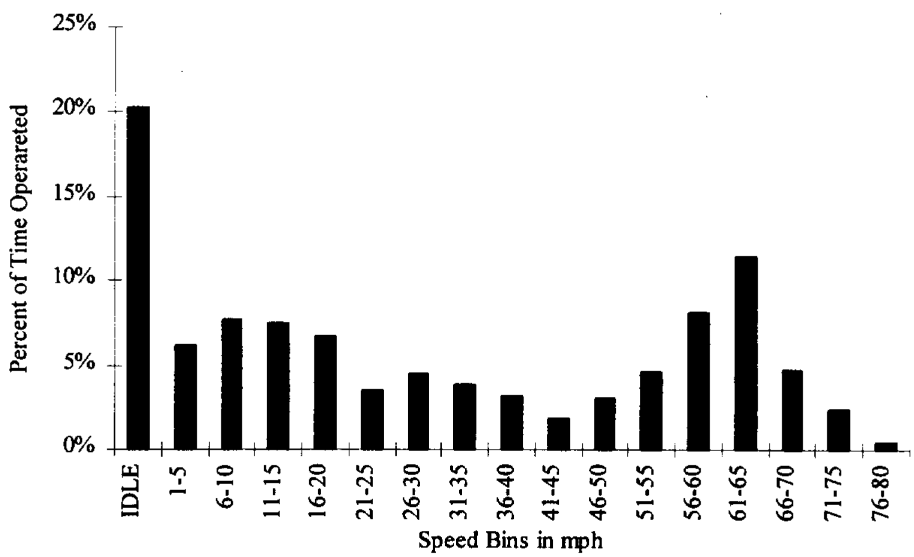


Fig. 5-1g
LHDG Vehicles Speed Profile



5.4.2 Average Daily Trips

A key operational characteristic of interest that was studied in this project was the average number of trips that different classes of trucks take per day. In conducting this analysis several key definitions must be understood in order to properly interpret the data. The first issue is the definition of a trip. A trip was defined as any period during which the vehicle was moved more than 0.001 of a mile. The 0.001 mile threshold was established because there were a few trucks that had a significant number of trip events of 0.001 miles and this was the limit of resolution of the device. Since these trips might actually measure rolling or very small movements of the truck that were not significant it was believed that including them in the data might bias the averages. Second definition of how averages were to be calculated. Each trip a truck took was considered an event for averaging purposes. All of the trips taken by a truck during the monitoring period were summed and this sum was divided by the number of days the data was collected..

Exhibit 5-6 shows the average number of trips per day by vehicle class. All trucks in the sample took an average of 13.4 trips per day. Medium-heavy trucks took the most trips per day at 19.8, followed by super-heavy-heavy trucks (20.0), light-heavy-trucks (14.9), and heavy-heavy trucks (4.6). The results may show some bias for the heaviest weight classes due to the under-representation of long haul trucks. The higher number of trips per day for medium-heavy trucks than light-heavy trucks appears to reflect a preponderance of delivery usage for the medium-heavy trucks (including 2 parcel pickup and delivery trucks) as compared to more varied usage including a number of general utility vehicles among the light-heavies.

This is further reflected when these two weight classes are disaggregated by fuel type. Gasoline medium-heavy trucks averaged 38.3 trips per day (2 out of the 3 trucks were parcel pickup and delivery trucks) as compared to only 14.9 trips per day for diesel medium-heavy trucks. Likewise, gasoline light-heavy trucks took 19.7 trips per day as compared to only 7.8 trips per day for diesel light-heavy trucks.

5.4.3 Trip Lengths and Average Trip Speeds

Average trip speed for a vehicle class was calculated by dividing the total distance covered in all the trips by all trucks in that class by the corresponding total time.

Average trip speeds are relatively consistent across all of the weight classes. There is some tendency towards higher average trip speeds with higher weight class, as shown in Exhibit 5-7. The one exception to this trend is heavy-heavy trucks which show the lowest average trip speed of all weight classes. To some extent this is due to the under-representation of long haul heavy-heavy trucks in the sample. Similarly, average trip speeds for super heavy trucks may reflect an under-representation of long haul trucks in this weight class. These appear to be the most significant sources of potential bias in the data.

Exhibit 5-6
Average Daily Trips

Vehicle Class	Trucks	Average Number of Trips per Day
All Trucks	31	13.4
Light-Heavy-Duty Trucks	7	14.9
Medium-Heavy-Duty Trucks	12	20.0
Heavy-Heavy-Duty Trucks	5	4.6
Super-Heavy-Heavy-Duty Trucks	7	10.4
LHD - Gasoline	4	19.7
MHD - Gasoline	3	38.3
LHD - Diesel	3	6.3
MHD - Diesel	9	14.9
HHD - Diesel	5	4.6
SHHD - Diesel	7	10.4

While the difference is slight, diesel trucks tend to have higher average trip speeds than do gasoline trucks in the same weight class. This difference was most pronounced for medium-heavy trucks in the sample. In this case the average trip speed for diesel trucks was 30.57 mph as compared to 23.82 mph for gasoline trucks. This does reflect the variation in usage of these trucks since medium-heavy gas trucks were used exclusively in local operations whereas the medium-heavy diesels include both local and short haul trucks.

5.4.4 Trip Behavior and Time of Day

The trip behavior analysis by time of day included a 24 hour distribution of trip starts, trip ends, time-on, time-off, resting time, vehicle miles traveled (VMT) and speed by vehicle weight category. These results will be used in the development of future emissions inventory model. In addition, mean values were determined for time-on for idle and non-idle trips, time-off, resting time and number of trip starts per day. These results will be used as target parameters in the development of test cycles for heavy duty trucks.

Exhibit 5-7
Average Trip Speed and Length

Weight Class	Average Trip[10] Length (minutes)	Average Trip Length (miles)	Average Speed (mph)
All Trucks	15.9	8.11	30.59
LHDGV	9.69	4.73	29.27
MHDGV	3.26	1.29	23.82
LHDDV	9.97	3.97	23.88
MHDDV	18.17	9.26	30.57
HHDDV	58.07	22.23	22.97
SHHDDV	16.88	10.55	37.51

For the purposes of this report, the following are definitions of the variables used in the analysis:

Idle Trip:
An idle trip is a key-on to key-off operation at a speed of zero miles per hour (mph) and the distance covered during that event is zero miles.

Non-Idle Trip
A non-idle trip is a key-on to key-off operation at a speed greater than zero mph. A non-idle trip may contain idle as part of the trip but the distance covered and the average trip speed are always greater than zero.

Time-on
Time-on will be used to calculate running emissions. It is the difference in time between the key-on and key-off events and it is applied to the hour the vehicle was turned on. If a vehicle's running time overflows to the next hour all of the time is counted in the hour when the vehicle started. For example, if a vehicle is turned on at 3:50 p.m. and turned off at 4:15 p.m. the total running time of 25 minutes would be applied to the 3:00 p.m. hour. Time-on will be used in estimating exhaust emissions and running losses. Since heavy-duty trucks frequently idle without moving, in future emissions model, running emissions for idle trips will be estimated separately from non-idle trips. For this reason, separate 24-hour time-on distributions are estimated for idle trips and non-idle trips

Time-Off
Time-off is the amount of time a vehicle is off prior to a trip start. It is the difference in time between the key-on event of the current trip and the key-off event of the previous

[10] Trips are defined as any time the vehicle traveled a distance greater than 0.001 miles.

trip, and is applied to the hour that the engine is turned on. For example, if a truck was turned off at 5:00 p.m. and then restarted at 7:00 am the next day, the 14 hour time-off would be applied to the start hour of 7:00 am. This time-off matrix will be used to calculate start emissions.

Resting Time
Resting time is the amount of time a vehicle will be off. It is the same as time-off except that it is applied to the hour the trip ended. The resting time will be used to calculate evaporative emissions such as hot-soak, diurnal and resting losses. In the example given for time-off, the 14 hour resting time would be applied to the trip end hour 5:00 p.m.

Trip Starts
Trips-starts is the number of times the vehicle was turned on during the respective hour. For example, if a trip started at 3:50 p.m. and ended at 4:15 p.m., the key-on event at 3:50 p.m. would be counted as one start applied to the 3:00 p.m. hour. Trip starts will be used to estimate start emissions.

Trip Ends
Trips-ends is the number of times the vehicle was turned off during the respective hour. Considering the example given above, the key-off event at 4:15 would be counted as one trip end applied to the 4:00 p.m. hour. Trip-ends will be used to estimate evaporative emissions.

VMT Distribution
Vehicle miles traveled (VMT) is the total distance traveled by a truck during a single trip and is applied to the hour the vehicle started. If a vehicle's travel spans more than one hour of the day then all the VMT will be assigned to the trip start hour. (e.g. a trip starts at 3:50 p.m. and ends at 5:15 p.m., then the VMT will be assigned to 3:00 p.m.)

VMT Distribution by Speed and Hour of the Day
A different matrix of VMT distribution by speed bin and hour of the day was determined by calculating the percent of miles traveled at different speed bins of 5 mph intervals (i.e. 19 speed bins from 0 to 90 mph) and hour of the day. VMT distribution in conjunction with speed correction factors will be used to correct base emission rates for speeds other than the speed of federal test procedure (FTP).

Below are tables and figures that show the results of analyzes of the instrument data for the variables explained above:

Exhibit 5-8 shows the average number of starts per day. Starts are distinguished from trips as any time the engine was turned on regardless of whether the truck was moved. Exhibits 5-9a to 5-9g show the starts distribution by time of day.

Exhibit 5-8
Average Number of Starts by Vehicle Weight and Fuel Category

Vehicle Class	Number of Starts per Day
LHDGV	19.2
MHDGV	45.8
LHDDV	8.2
MHDDV	14.6
HHDDV	7.5
SHHDDV	14.1

Fig. 5-2a
Starts Distribution by time of Day - SHHDDV

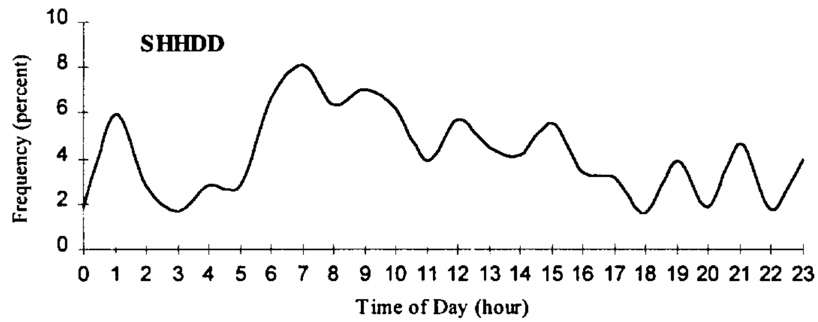


Fig. 5-2b
Starts Distribution by time of Day - HHDDV

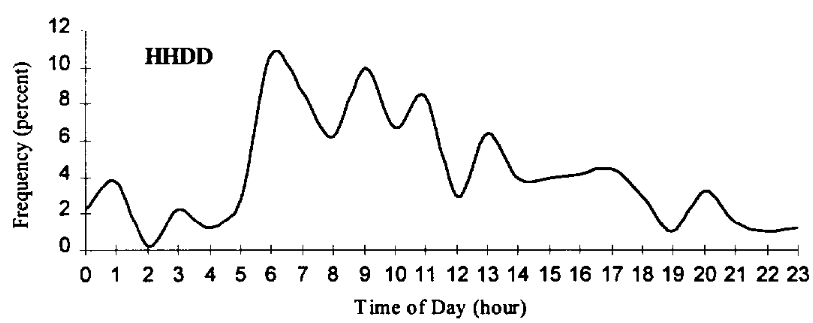


Fig. 5-2c
Starts Distribution by time of Day - MHDGV

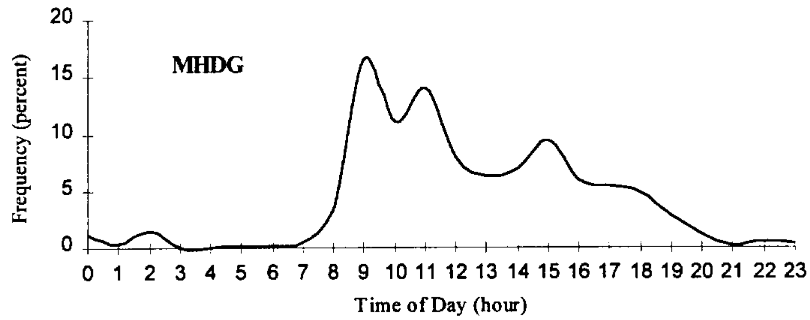


Fig. 5-2d
Starts Distribution by time of Day - MHDDV

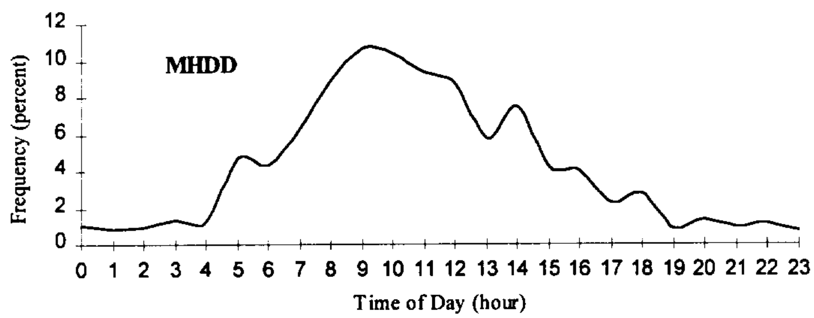


Fig. 5-2e
Starts Distribution by time of Day - LHDGV

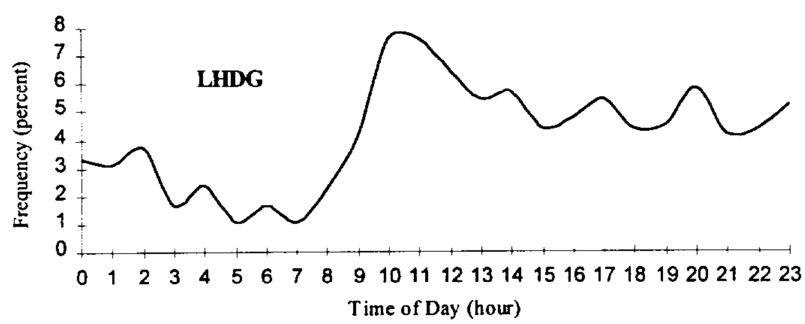
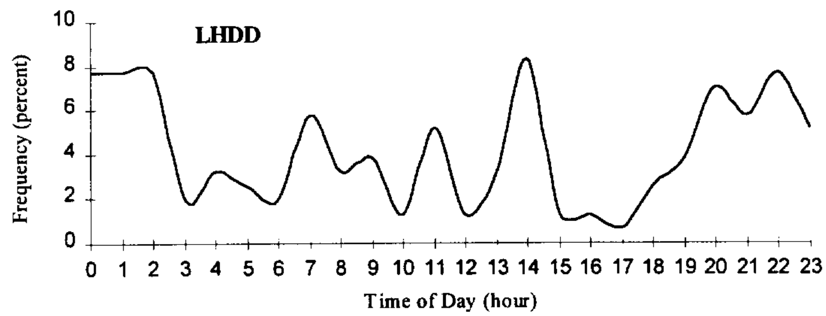


Fig. 5-2f
Starts Distribution by time of Day - LHDGV



Figures 5-3a to 5-3f show VMT distribution by time of day. It indicates the percent of the daily VMT of that vehicle class traveled at that hour of the day. Figures 5-4a to 5-4f show VMT distribution by speed and time of the day. Figures 5-5a to 5-5f and figures 5-6a to 5-6f respectively show time-on and time-off distribution by time of day .

Fig. 5-3a
VMT Distribution by time of Day - SHHDDV

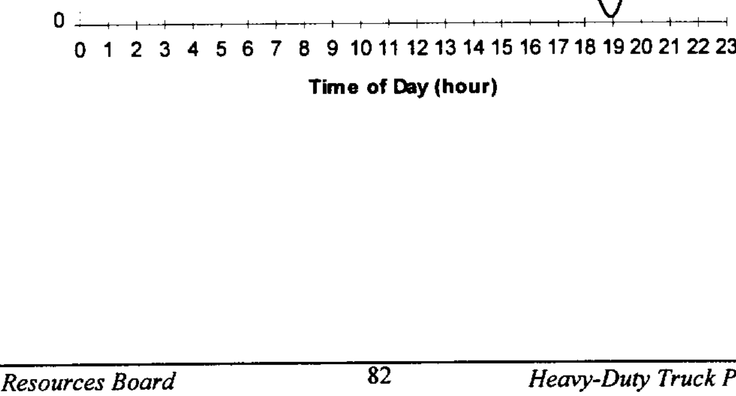


Fig. 5-3b
VMT Distribution by time of Day - HHDDV

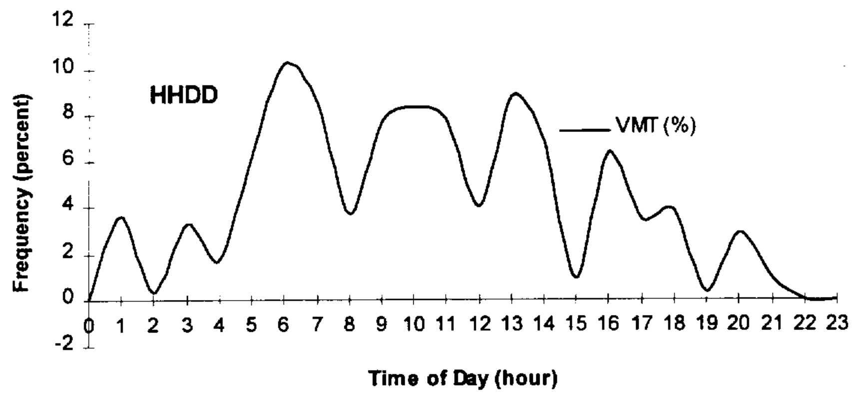


Fig. 5-3c
VMT Distribution by time of Day - MHDDV

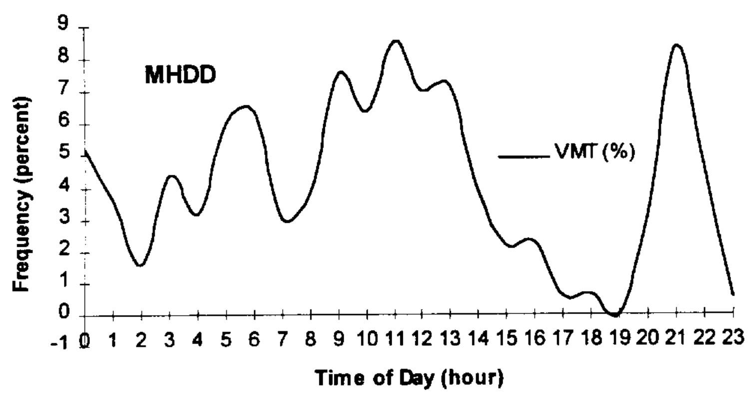


Fig. 5-3d
VMT Distribution by time of Day - MHDGV

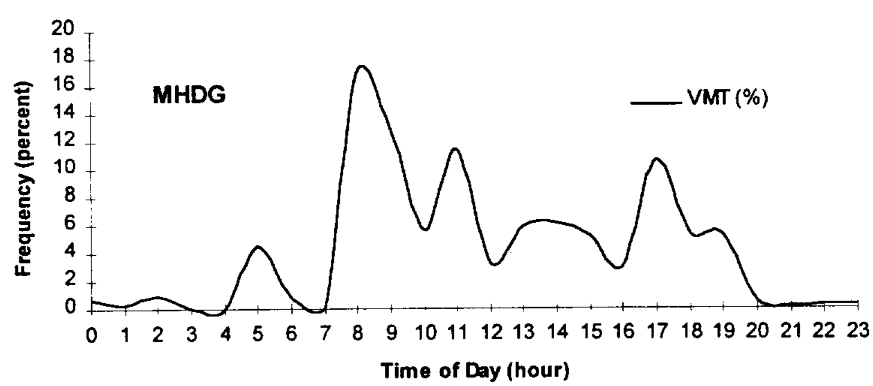


Fig. 5-3e
VMT Distribution by time of Day - LHDDV

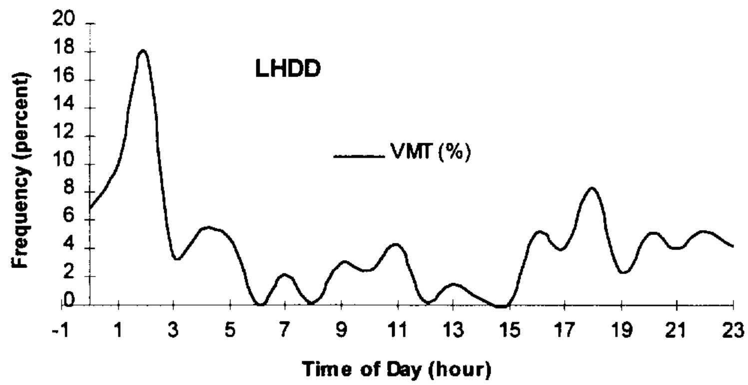


Fig. 5-3f
VMT Distribution by time of Day - LHDGV

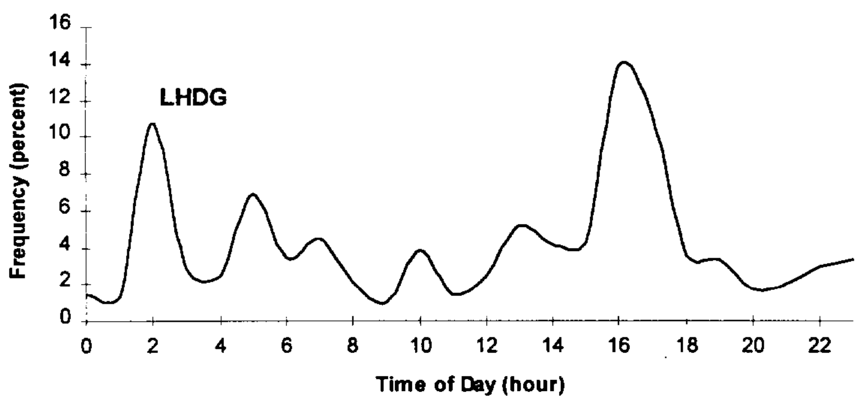


Fig. 5-4a
VMT Distribution by Speed and Time of Day - SHHDDV

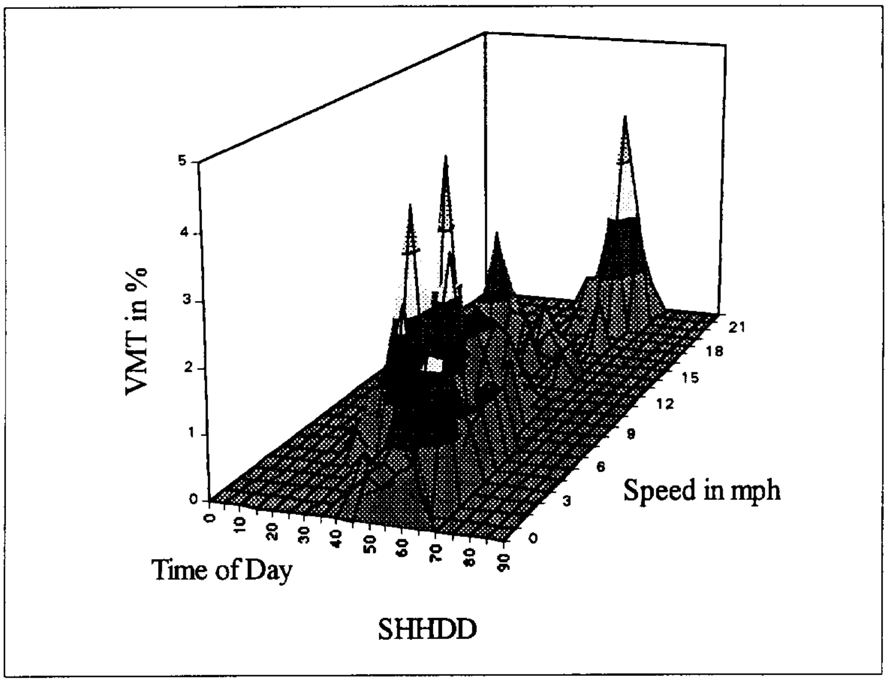


Fig. 5-4b
VMT Distribution by Speed and Time of Day - HHDDV

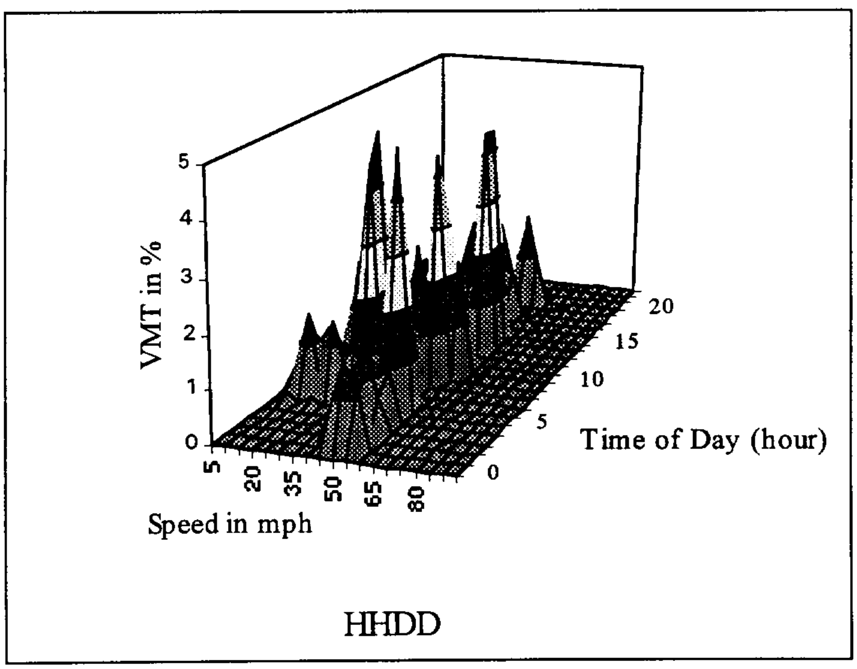


Fig. 5-4c
VMT Distribution by Speed and Time of Day - MHDDV

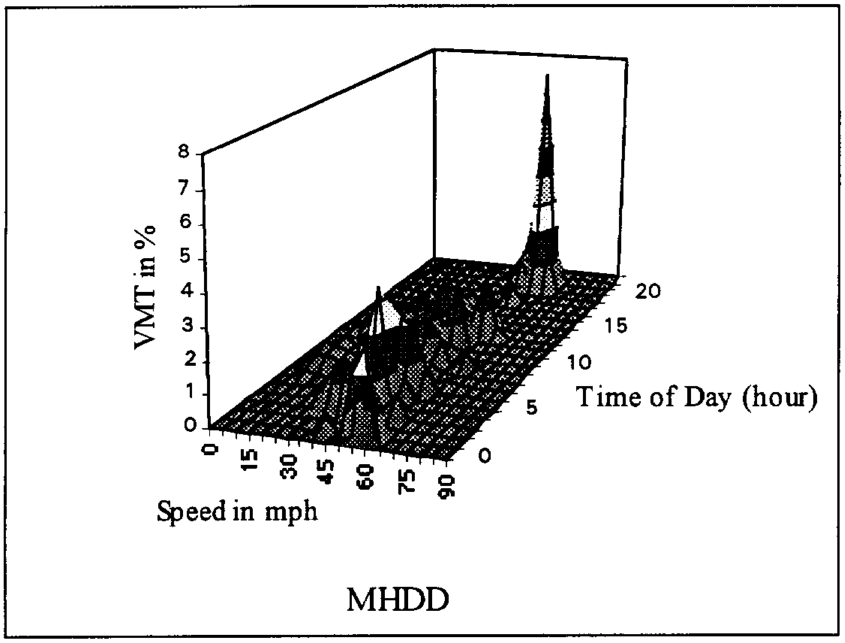


Fig. 5-4d
VMT Distribution by Speed and Time of Day - MHDGV

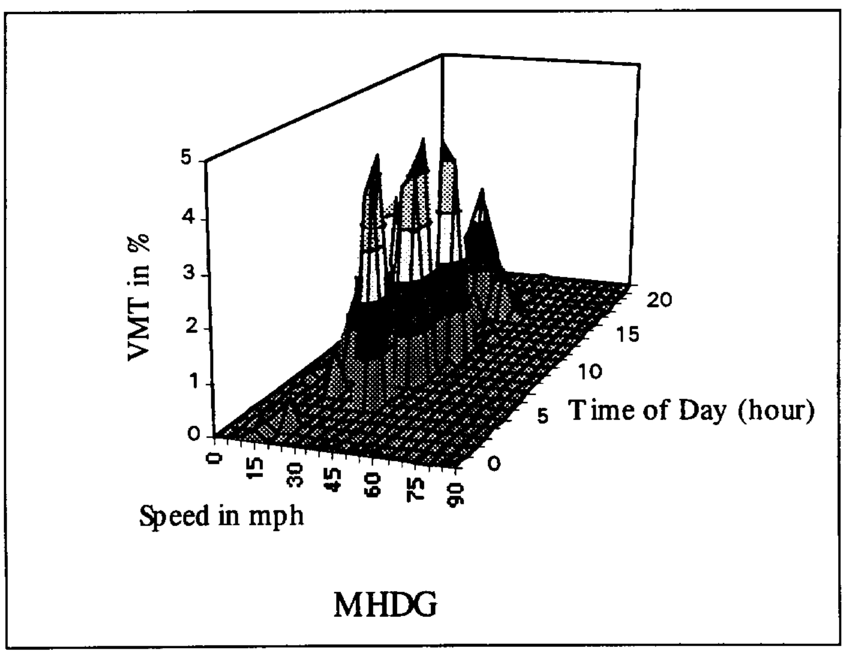


Fig. 5-4e
VMT Distribution by Speed and Time of Day - LHDDV

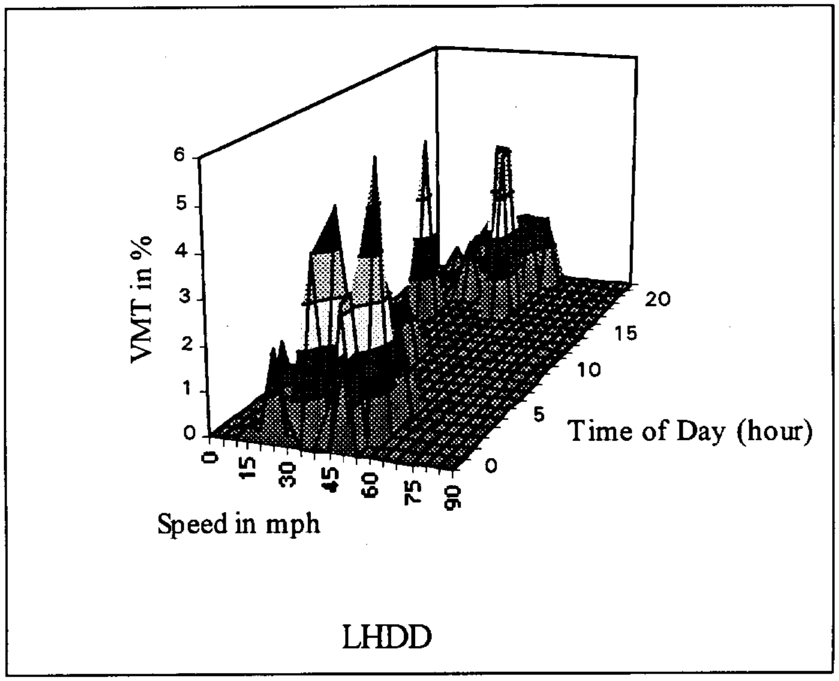


Fig. 5-4f
VMT Distribution by Speed and Time of Day - LHDGV

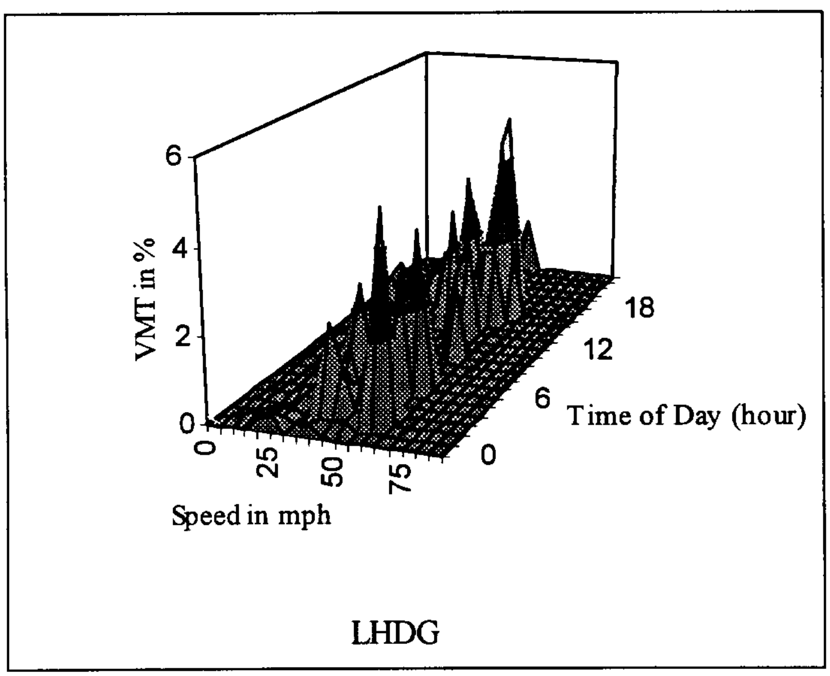


Fig. 5-5a
Time-On Distribution by Time of Day (Non-Idle Trips) - SHHDDV

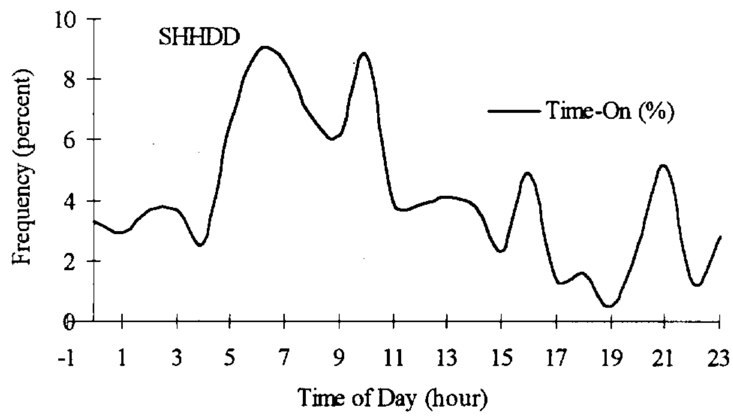


Fig. 5-5b
Time-On Distribution by Time of Day (Non-Idle Trips) - HHDDV

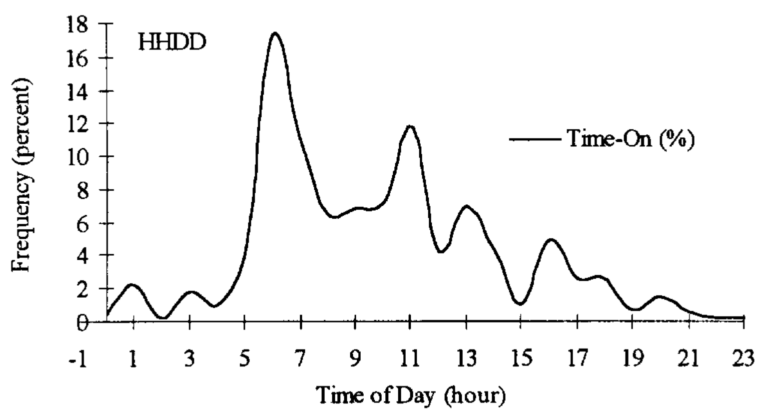


Fig. 5-5c
Time-On Distribution by Time of Day (Non-Idle Trips) - MHDDV

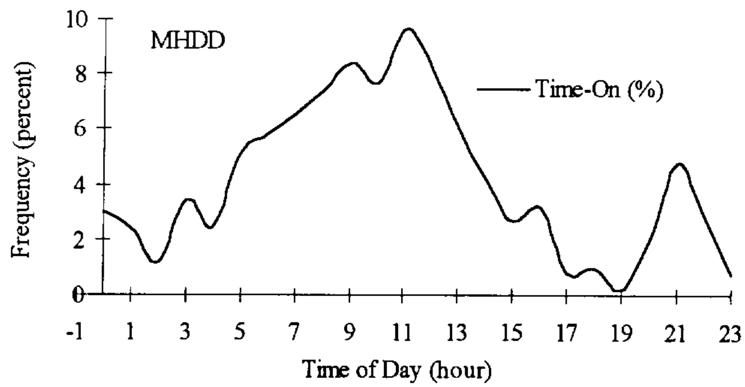


Fig. 5-5d
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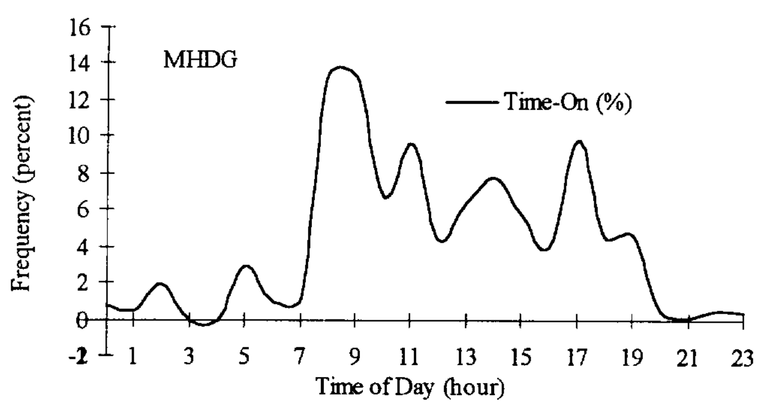


Fig. 5-5e
Time-On Distribution by Time of Day (Non-Idle Trips) - LHDDV

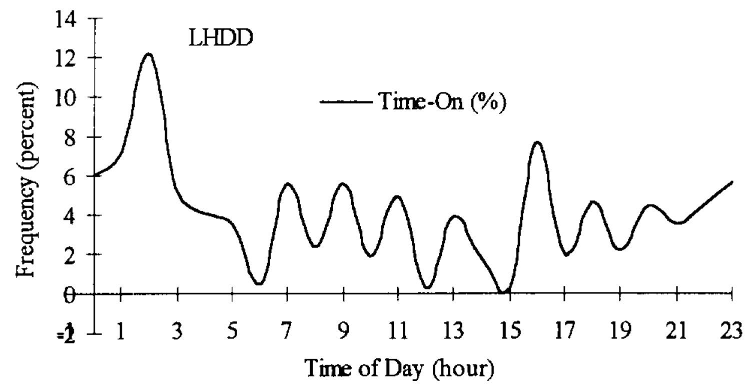


Fig. 5-5f
Time-On Distribution by Time of Day (Non-Idle Trips) - LHDGV

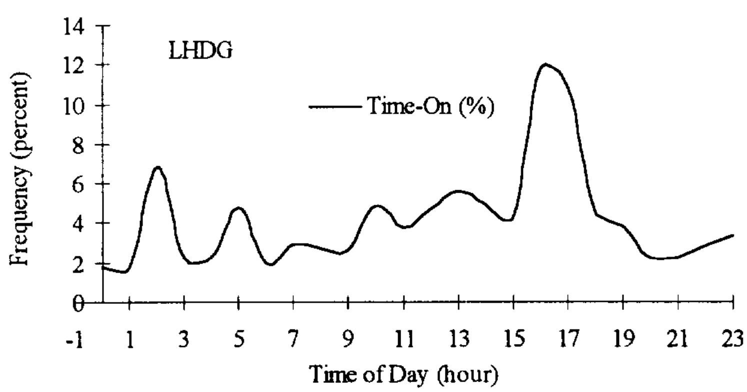


Fig. 5-6a
Time-Off Distribution by Time of Day - SHHDDV

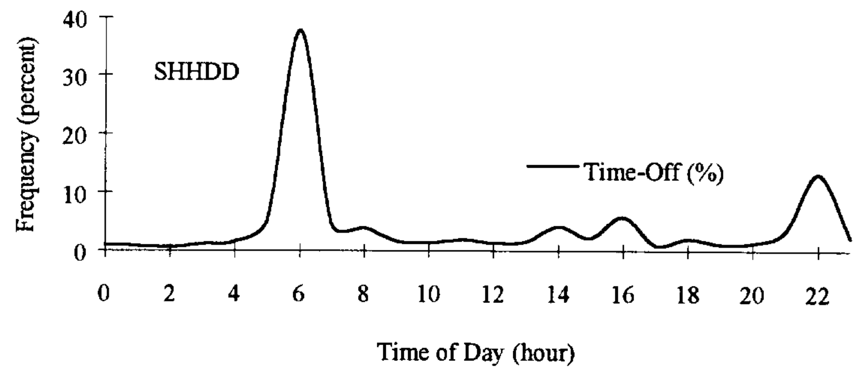


Fig. 5-6b
Time-Off Distribution by Time of Day - HHDDV

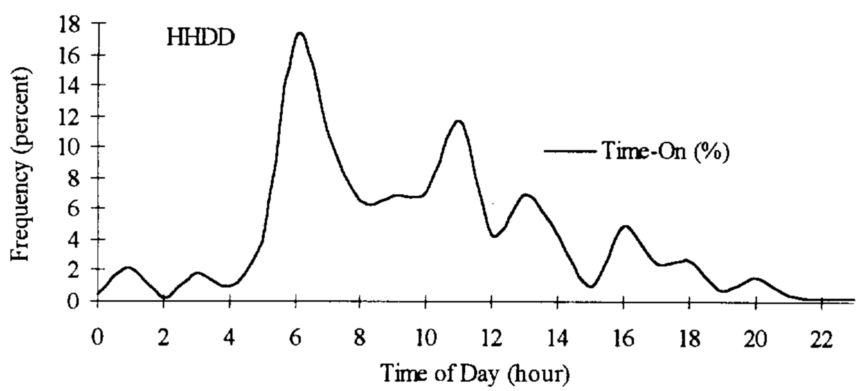


Fig. 5-6c
Time-Off Distribution by Time of Day - MHDDV

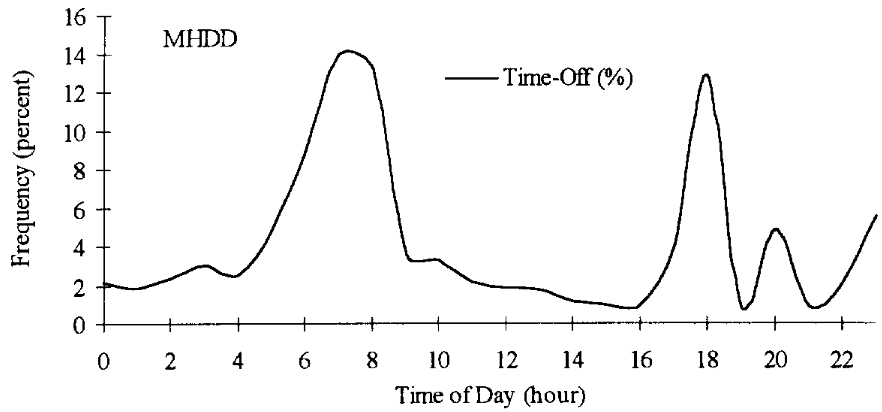


Fig. 5-6d
Time-Off Distribution by Time of Day - MHDGV

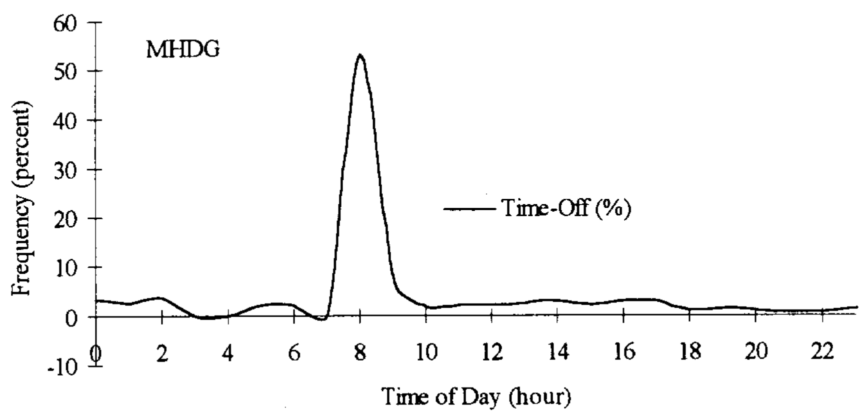


Fig. 5-6e
Time-Off Distribution by Time of Day - LHDDV

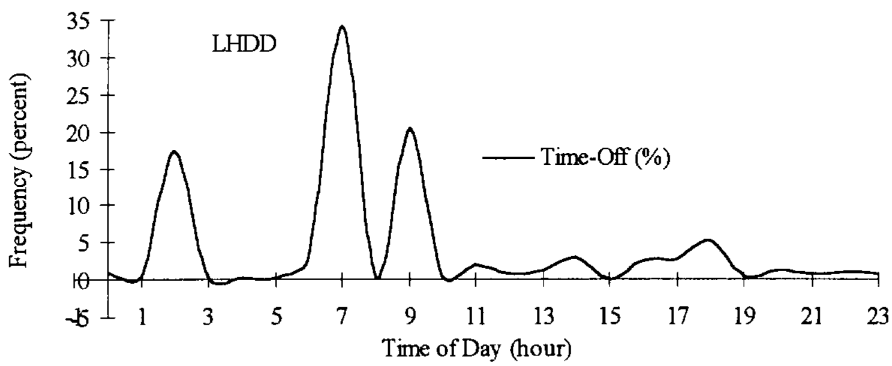
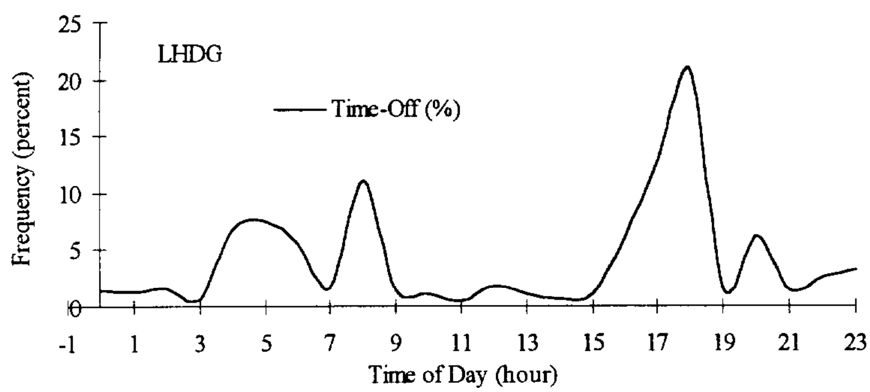


Fig. 5-6f
Time-Off Distribution by Time of Day - LHDGV



5.5 CONCLUSIONS OF THE MONITORING PROGRAM

The data collected from in-use trucks should provide a rich data base from which to work in developing modifications to existing models, emission test cycles, and new research programs on truck activity. In general, the instrumentation functioned well in the field although the load measurement techniques for second-by-second data had some serious shortcomings (particularly the manifold pressure measurements for diesel trucks). Alternative methods for measuring vehicle loads for heavy-duty diesel trucks should be pursued for future studies.

Vehicle procurement is an especially challenging aspect of designing a useful data collection effort and a direct working relationship with an industry advisory committee and industry trade groups would greatly enhance future attempts to collect the types of data collected in this project. Cooperation from CTA was helpful in convincing certain fleets to participate in the program; a more active role for industry representatives would be that much more helpful. Better sampling frames would also help the sampling process. The inability to access DMV registration records is a major obstacle to proper sampling. Other states have made these records available for government sponsored transportation research. We recommend that ARB work with other interested agencies and DMV to see if this policy could be changed.

Given the highly variable driving patterns that are associated with specific functional use categories (e.g. parcel delivery vs. other types of delivery, construction, late night distribution hauls) a much larger sample of trucks is needed to establish average speed profiles and trip behavior with any degree of statistical accuracy.

Another problem that should be addressed in future data collection is the impact of facility type and geographic location of the trips. Clearly, local delivery traffic in downtown Los Angeles will exhibit different characteristics than it will in Victorville. Because of the limited number of vehicles sampled and the constraints in the sampling procedure, these types of differences in driving location and facility are difficult to detect. This is particularly critical for speed profiles and average speed data. Methodologies which combine this type of on-road data collection with other traffic flow information could be helpful in expanding the usefulness of data collected with on-board computers. For example, studies which use GPS navigation systems to track vehicle routes and which sample based on geographic location and road facility types that are used could help connect on-road data collection efforts with other traffic flow studies that could help extend both of these types of data. This type of information could then be presented in a GIS format to show the impact of geography and facility usage on average speeds and trip behavior. ARB should consider this approach for future projects of this type.

The data do show some reasonable patterns with respect to speed profiles, average daily trips, and times of trip-making that appear to be correlated with truck weight classes suggesting that weight class and usage may be highly correlated. These results also suggest that developing alternative emission test cycles for each weight class may be appropriate. Another significant finding with respect to weight class and driving behavior is that super-heavy trucks did exhibit some unique driving behaviors. Usages that involve more high speed driving and overnight long hauls (as opposed to long hauls in a single day) appear to be more likely to be found in super heavy trucks than in the general heavy-heavy population. However, the data on this point is somewhat inconclusive given the relatively small number of trucks included in this study.

We believe that ARB should consider this study a beginning and that additional data should be collected to validate the preliminary findings from this research. Given the limitations on numbers of trucks instrumented and the impacts this has on statistical validity of the results it is clear that additional research will be needed. Nonetheless, these data represent an important first step in characterizing the operational characteristics of on-road HDTs.

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