Review and Analysis of Heavy-Duty Truck Activity Data

Final Report

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Disclaimer

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

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Executive Summary

Emissions calculated with the California Air Resources Board's EMFAC model show that heavy-heavy-duty diesel trucks (HHDDTs) contribute more emissions of the oxides of nitrogen (NO_x) and particulate matter (PM) than the number of vehicles might suggest. The primary reason for the high emissions is that HHDDTs have few emission controls and high emission factors. Emissions are heavily dependent on driving behavior as well as to changes in the programming of the on-board computer in modern electronic fuel injected HHDDT vehicles. In-use driving behavior and the proportion of reprogrammed vehicles in the on-road HHDDT fleet are of significant interest to the ARB and there is the need to quantify these factors.

This report describes the results of the University of California, Riverside's (UCR) creation and data-mining analysis of a database created from 270 electronic downloads from in-use heavy-duty diesel vehicles that were obtained by the ARB through a private contractor. The goal of this project was to explore the utility of this type of data for research into heavy-duty diesel vehicles fleet characteristics as well as activity analysis. This measurement approach, taking data from the on-board computer of in-use vehicles, provides a low cost alternative to more traditional GPS and data logger studies of in-use vehicles.

Significant results included:

- Data input for 270 vehicles
  - General engine information
  - General vehicle operation information
  - Detailed activity information on 45 CAT vehicles
- Data mining database created in SAS Enterprise Miner
  - Preliminary analysis of factors affecting Fuel Economy
  - Horsepower/Fuel Economy relationship explored in greater detail
  - Idle Time/Fuel Economy preliminary analysis
- Statistical analysis of vehicle fleet characteristics
  - Manufacturer
  - Engine Model
  - Horsepower
  - Torque
  - Model Year
- Statistical analysis of general vehicle activity data
  - Total fuel used
  - Total time of operation
  - Idle time percent
  - Fuel economy
- Preliminary analysis of detailed vehicle activity data

1. Introduction

1.1 Background on Emissions

The California Air Resources Board estimates that heavy-duty diesel (HDD) vehicles account for about 30% of the oxides of nitrogen (NOx) and 65% of the particulate matter (PM) emitted by mobile sources while comprising only 2% of the on-road vehicle fleet (ARB, 2002). In addition, in many locations they are major contributors to the overall emissions inventory, accounting for over 50% of the NOx and PM (Lloyd and Cackette 2001, Yanowitz et al.,2000). These vehicles will continue to play a major emissions inventory role with increases in goods movement along with their high durability and reliability. ARB has categorized a number of truck and bus sectors, including six HDD classes:

Category	Weight	Population
Light heavy-duty trucks 1	8,501- 10,000 lbs	272,000
Light heavy-duty trucks 2	10,001- 14,000 lbs.	84,000
Medium heavy- duty trucks	14,001- 33,000 lbs.	266,000
Heavy heavy-duty trucks	33,001+ lbs	175,000
School buses	All	30,000
Urban buses	All	14,000

NO_x emissions from these categories, calculated with EMFAC 2000, are dominated by heavy-heavy-duty trucks. VMT is a fairly good predictor of NO_x by category but vehicle population is not particularly useful because of the very different types of operational conditions between the vehicle classes. For example, although the population of medium-duty trucks equals that of the heavy-heavy-duty diesel (HHDD) trucks, their total NO_x emissions are only 25% of those emitted by the HHDD by comparison.

1.2 Electronic Engine Downloads

Modern diesel engines have rather sophisticated computers that control engine operation and allow manufacturers to program changes in efficiency and also allow for archiving of operating parameter information such as speed and RPM. The original equipment manufacturers (OEMs) use this information to learn about typical vehicle operation as well as to monitor vehicle usage to determine if warranty repair service will be approved. A large number of variables are available on the engine downloads from electronically controlled engines. The engine setting variables available on the Caterpillar engine downloads are presented in Table 1. A large data set was collected during the M17 program consisting of over 300 HHDDT engine control unit (ECU) electronic downloads. These were collected from in-use vehicles. The specific data available from the ECU varies by manufacturer, but generally includes engine identification and vehicle operational summaries as well as information on the current engine control program and the date when it was installed.

While the different manufacturers record many of the same engine variables, the functions and the specific variables are not uniform across manufacturers. Because of this lack of uniformity in variables,

names, and data format, the job of compiling the data into a format useful for analysis will be labor intensive.

Heavy-duty diesel engines have been electronically controlled since the late 1980's. Part of the electronic control systems manages engine operation and another part collects and stores data on vehicle use. As the electronics have become more sophisticated they have enabled greater levels of control of engine operation (optimization of fuel use on extended cruises for example) as well as greater levels of data collection and storage. Modern electronic control systems collect and can provide operating information (temperatures, pressures, fuel consumption), customer programmable information (idle speed, cruise control mode), as well as diagnostic information. Engine manufacturers provide various specialized software systems for retrieving the data from these on-board computer systems using laptops or handheld computers. The specialized software and interface hardware are unique for each manufacturer.

A large number of variables are available on the engine downloads. The specific variables available vary from manufacturer to manufacturer, and across model years within manufacturers. The Caterpillar Electronic Technician (ET) software was used exclusively for the CAT vehicles. The ET program permits access to a range of diagnostic and archived engine and vehicle activity data. The engine setting variables available on a 1999 Caterpillar engine download are presented in Table 1 for UCR's HHDD vehicle.

Cat Electronic Technician Cat ET2002A		
Parameter	Parameter	Parameter
Vehicle ID	Idle Vehicle Speed Limit	Maintenance Indicator Mode
Engine Serial Number	Idle RPM Limit	PM1 Interval
ECM Serial Number	Idle/PTO RPM Ramp Rate	Engine Oil Capacity
Personality Module Part Number	Idle/PTO Bump RPM	Trip Parameters
Personality Module Release Date	Dedicated PTO Parameters	Fuel Correction Factor
Personality Module Code	PTO Configuration	Dash - Change Fuel Correction Factor
ECM Date/Time	PTO Top Engine Limit	Dash - PM1 Reset
Description	PTO Engine RPM Set Speed (0 = Off)	Dash - Fleet Trip Reset
Selected Engine Rating	PTO Engine RPM Set Speed A	Dash - State Selection
Rating Number	PTO Engine RPM Set Speed B	Theft Deterrent System Control
Rating Type	PTO to Set Speed	Theft Deterrent Password
Multi-Torque Ratio	PTO Cab Controls RPM Limit	Quick Stop Rate
Advertised Power	PTO Kickout Vehicle Speed Limit	Vehicle Activity Report Parameters
Governed Speed	Torque Limit	Minimum Idle Time (0 = Off)
Rated Peak Torque	PTO Shutdown Time (0 = Off)	Driver Reward
Top Engine Speed Range	PTO Shutdown Timer Maximum RPM	Driver Reward Enable
Test Spec	PTO Activates Cooling Fan	Input Selections
Test Spec with BrakeSaver	Engine/Gear Parameters	Fan Override Switch
ECM Identification Parameters	Lower Gears Engine RPM Limit	Ignore Brake/Clutch Switch
Vehicle ID	Lower Gears Turn Off Speed	Torque Limit Switch
Engine Serial Number	Intermediate Gears Engine RPM Limit	Diagnostic Enable
ECM Serial Number	Intermediate Gears Turn Off Speed	Remote PTO Set Switch
Personality Module Part Number	Gear Down Protection RPM Limit	Remote PTO Resume Switch
Personality Module Release Date	Gear Down Protection Turn On Speed	PTO Engine RPM Set Speed Input A
Security Access Parameters	Top Engine Limit	PTO Engine RPM Set Speed Input B
Total Tattletale	Top Engine Limit with Droop	Starting Aid On/Off Switch
Last Tool to change Customer Parameters	Low Idle Engine RPM	Two Speed Axle Switch
Last Tool to change System Parameters	Transmission Style	Cruise Control On/Off Switch
ECM Wireless Communications Enable	Eaton Top 2 Override with Cruise Switch	Cruise Control Set/Resume/Accel/Decel Switch
Vehicle Speed Parameters	Top Gear Ratio	Clutch Pedal Position Switch
Vehicle Speed Calibration	Top Gear Minus One Ratio	Retarder Off/Low/Med/High Switch
Vehicle Speed Limit	Top Gear Minus Two Ratio	Service Brake Pedal Position Switch #1
VSL Protection	Timer Parameters	Accelerator Pedal Position
Tachometer Calibration	Idle Shutdown Time (0 = Off)	Output Selections
Soft Vehicle Speed Limit	Idle Shutdown Timer Maximum RPM	Engine Running Output
Low Speed Range Axle Ratio	Allow Idle Shutdown Override	Engine Shutdown Output
High Speed Range Axle Ratio	Minimum Idle Shutdown Outside Temp	Auxiliary Brake
Cruise Control Parameters	Maximum Idle Shutdown Outside Temp	Starting Aid Output
Low Cruise Control Speed Set Limit	A/C Switch Fan On-Time (0 = Off)	Fan Control Type
High Cruise Control Speed Set Limit	Fan with Engine Retarder in High Mode	Passwords
Engine Retarder Mode	Engine Retarder Delay	Customer Password #1
Engine Retarder Minimum VSL Type	Smart Idle Parameters	Customer Password #2
Engine Retarder Minimum Vehicle Speed	Battery Monitor and Engine Control Voltage	Data Link Parameters
Auto Retarder in Cruise (0 = Off)	Engine Monitoring Parameters	Powertrain Data Link
Auto Retarder in Cruise Increment	Engine Monitoring Mode	System Parameters
Cruise/Idle/PTO Switch Configuration	Engine Monitoring Lamps	Personality Module Code
SoftCruise Control	Coolant Level Sensor	FLS
Idle Parameters (Old PTO)	Maintenance Parameters	FTS

Table 1. Caterpillar Engine Variables Available on Downloads

2. Methodology

2.1. Data Download Collection

A large data set was collected during the M17 program consisting of over 300 HHDDT engine control unit (ECU) electronic downloads. These were in-use data collected from vehicles that were at an independent repair shop. The specific data available from the ECU varies by manufacturer and by model year, but generally includes identification of engine components and vehicle operational summaries as well as information on the current engine control program and the date when it was installed. The electronic inspections represent a grab sample of data from the three major engine manufacturers: Caterpillar, Cummins and Detroit Diesel. The software is intended for fleet operators and repair shops in order to monitor driver activity and customize or limit engine operation to meet specific owner requirements.

Data downloads were collected from the electronic control system using the appropriate software for each manufacturer and saved as Adobe Acrobat pdf files with each vehicle separated by a blank page. Print quality, and thus pdf page quality varied from data sheet to data sheet with some vehicles having easy to read text while others were more difficult. Text alignment varied from vehicle to vehicle as well which precluded using standard optical character recognition software to automate the data entry process. Examples of data from typical Caterpillar (Figure 1), Cummins (Figure 2), and Detroit Diesel (Figure 3) are provided below.

Cat Electronic Technician ET3.2 (OCT00)
Configuration

3/3/2002 5:17 PM Page 1

3406E Truck (5EK19183)

Parameter	Value
Vehicle ID	9561
Engine Serial Number	5EK19183
ECM Serial Number	15740122CA
Personality Module Part Number	1469244-00
Personality Module Release Date	MAR97
Personality Module Code	23
ECM Date/Time	Unavailable

Description	Value	Unit	TT
Selected Engine Rating			
Rating Number	1		1
Rating Type	Multi-Torque		
Advertised Power	355 HP		
Governed Speed	1800 RPM		
Rated Peak Torque	1450 lb-ft @ 1200 RPM		
Top Engine Speed Range	1600 - 2120 RPM		
Test Spec	02T7481-00		
Test Spec with BrakeSaver	NONE		
ECM Identification Parameters			
Vehicle ID	9561		2
Engine Serial Number	5EK19183		
ECM Serial Number	15740122CA		
Personality Module Part Number	1469244-00		
Personality Module Release Date	MAR97		
Security Access Parameters			
Total Tattletale	63		
Last Tool to change Customer Parameters	P9006314		
Last Tool to change System Parameters	ET002414		
ECM Wireless Communications Enable	No		0
Vehicle Speed Parameters			
Vehicle Speed Calibration	32866	PPM	2
Vehicle Speed Limit	70	MPH	6
VSL Protection	1442	RPM	3
Tachometer Calibration	113.0	PPR	1
Soft Vehicle Speed Limit	No		3
Cruise Control Parameters			
Low Cruise Control Speed Set Limit	30	MPH	1
High Cruise Control Speed Set Limit	70	MPH	3
Engine Retarder Mode	Latch		1
Engine Retarder Minimum VSL Type	Hard Limit		0
Engine Retarder Minimum Vehicle Speed	0	MPH	0
Auto Retarder in Cruise (0 = Off)	0	MPH	0
Auto Retarder in Cruise Increment	2	MPH	0
Cruise/Idle/PTO Switch Configuration	Set/Accel-Res/Decel		1

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Figure 1 Example Caterpillar Data Download Sheet 1

Date Printed: Saturday, December 08, 2001 11:14:17 AM **Page 1**

CURRENT JOB IMAGE REPORT

Cummins Engine Company INSITE Professional - ISM

Job Number: 0-011120-132552 (Image Number: 2)
Job Date: Tuesday, November 20, 2001
Vehicle Unit Number:
Customer:
Description:

System ID/Dataplate

Advertised Power:	330 hp
RPM at Advertised Power:	0 rpm
Governed Speed:	1800 rpm
Peak Torque:	1350 ft·lb
RPM at Peak Torque:	1200 rpm
Fuel Code / Pump Part Number:	0XH46
Critical Parts List (CPL):	2608
Percent Torque Rise:	0
Engine Make:	CMMNS
Engine Model:	ISM 330
Engine Serial Number:	34952714
Engine Build Date:	30099
Customer Name:	
Customer Location:	
Customer Unit Number:	
ECM Make:	CMMNS
ECM Part Number:	3681404
ECM Serial Number:	11007777
ECM CODE:	L20299.03
ECM Voltage High:	0 V
ECM Voltage Low:	0 V
Eng. Cal Time/Date Stamp:	3/19/99 1:49:07 PM
SC Option:	20068
DO Option:	2103
Calibration Voltage High:	0 V
Calibration Voltage Low:	0 V
Other Options:	
OEM Name:	NA
OEM Vehicle or Equip. Model:	None
VIN or Equipment S/N:	1FUWDMCA2YLF13735
Vehicle or Equipment Year:	

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Figure 2 Example Cummins Data Download Sheet 1

Detroit Diesel Diagnostic Link - Engine Configuration Data
Printed on February 22, 2002

DYNOMASTER
10830-A SOUTH HARLAN RD.
FRENCH CAMP ., CA 95231
209 234-1963

Vehicle Unit Number:
Engine Serial Number: 06R0606777

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Engine page:

Engine Series	Series 60
Engine serial number:	06R0606777
VIN:	1FUJA6CG71LH69877
Engine model:	6067BK60
Idle speed RPM:	600
Rated BHP:	500
Peak Torque ft-lb:	1650
Rated engine RPM:	2110
Peak torque RPM:	1200
LSG droop RPM:	125
ECM data page:	**Master**
Rating group (6N4M#):	7246
Rating family (6N4D#):	7024
Application family (6N4C#):	125
EPA Certification:	1157
ECM serial number:	VH600VM8
ECM software level:	29.01
Shared version:	110
Rating version:	110

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Figure 3 Example Detroit Diesel Data Download Sheet 1

2.2. Database Construction

The data sheets obtained by the ARB were printed and entered by hand into a Microsoft Access Database using standardized entry forms for each of the three manufacturers. The variable names differed somewhat from manufacturer to manufacturer. The variables entered for each of the three

manufacturers are listed in Table 2. Individual model years also differed within manufacturers, and not all vehicles within each manufacturer had all listed variables.

Initial data input for this project involved manual transcription of pdf files into MS Excel data files for each manufacturer. For the general data fields, a MS Access program was used for data entry, with the data output as MS Excel files. For the activity data the pdf files were input directly into the Excel files. A total of 270 vehicles were successfully input into the database.

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

Cummins	DDC	CAT
Vehicle #	Vehicle #	Vehicle #
Date	Date	Date
Manufacturer	Manufacturer	Manufacturer
Engine Model	Engine Model	Engine Model
VIN	VIN	VIN
Engine Serial Number	Engine Serial Number	Engine Serial Number
ECM Serial Number	ECM Serial Number	ECM Serial Number
Advertised Power	Advertised Power	Advertised Power
Governed Speed	Governed Speed	Governed Speed
Peak Torque	Peak Torque	Peak Torque
RPM at Peak Torque	RPM at Peak Torque	RPM at Peak Torque
Total Time	Total Time	Total Time
Total Distance	Total Distance	Total Distance
Total Fuel Used	Total Fuel Used	Total Fuel Used
Total Fuel Economy	Total Fuel Economy	Total Fuel Economy
Total Idle Fuel	Total Idle Fuel	Total Idle Fuel
Total Idle Time	Total Idle Time	Total Idle Time
% Time at Idle	% Time at Idle	% Time at Idle
Total PTO Fuel	Total PTO Fuel	Total PTO Fuel
Total PTO Time	Total PTO Time	Total PTO Time
% Time at PTO	Total Brake Time	% Time at PTO
Total Brake Time	Total Cruise Time	Avg Load Factor
Total Brake Distance	% Time at Cruise	Avg Vehicle Speed
Total Cruise Time	Total Fuel Economy	Max Vehicle Speed
Total Cruise Fuel	% Time at Idle	Max Engine Speed
% Time at Cruise	% Time at PTO	Rating Number
Engine average load factor	% Time at Cruise	Rating type
Trip average vehicle speed		Total Fuel Economy
Brake actuations/1000 miles		% Time at Idle
Total top gear fuel		% Time at PTO
Total top gear time		
Total sweet spot fuel		
Total sweet spot time		
% Time at Idle		
% Time at PTO		
% Time at Cruise		

The VIN code of each vehicle, when available, was decoded to obtain the model year of each vehicle using the 10th digit (Table 3).

Table 3 Conversion code for Model Year from VIN 10th digit.

1980 =A
1981=B
1982=C
1983=D
1984=E
1985=F
1986=G
1987=H
1988=J
1989=K
1990=L
1991=M
1992=N
1993=P
1994=R
1995=S
1996=T
1997=V
1998=W
1999=X
2000=Y
2001=1
2002=2
2003=3
2004=4

2.3. Quality Assurance

Quality assurance checks were performed after data entry to identify suspicious values from the data entry process as well as from the download forms. A 10% randomly chosen sub-sample was entered twice and cross-checked for data entry errors. All VIN codes were entered as listed on the data downloads, however many were either missing of contained invalid codes.

2.4 Statistical Analysis

Descriptive statistics were obtained using Statview software (SAS Inc. 1999) read from MS Excel data files. The data mining analysis was conducted using SAS Enterprise Miner software (SAS Inc. 2004), a set of software tools designed for data mining of large data sets. SAS Enterprise Miner was selected for this project because of its ease of use, wide availability of SAS software, and because of the powerful selection of statistical tools available in the package.

Enterprise Miner software is an integrated product that provides an end-to-end solution for data mining. A graphical user interface (GUI) provides a user-friendly front-end to the SEMMA data mining process. The data mining process is driven by a process flow diagram, which can be modified and saved for future use or to serve as a starting point for future analysis by other workgroups.

Statistical tools include clustering, self-organizing maps / Kohonen, variable selection, trees, linear and

logistic regression, and neural networking. Data preparation tools include outlier detection, variable transformations, data imputation, random sampling, and the partitioning of data sets (into train, test, and validate data sets). In this program UCR applied the basic tools for data mining, but additional research using the database created in this project would likely make use of the full spectrum of data mining tools available in the package.

3. Results

3.1 Engine Properties: Manufacturer, Model, Year, Power, Peak Torque

The initial analysis focused on basic descriptive statistics of the vehicle fleet in the database. Summary statistics were compiled for all three manufacturers together on common variables and individually for variables not in common. The overall count of vehicles broken down by manufacturer is presented in Table 4.

Table 4 Overall Manufacturers distribution

	Count
CAT	72
CUMMINS	108
Detroit Diesel	90
Total	270

Many of the vehicles had missing or incomplete VIN codes which prevented identification of the engine model year. Thus Table 5 only shows 177 of the 270 vehicles shown in Table 4. Vehicles having VIN code model years prior to the introduction of electronic engines or engines manufactured after the observation date were assumed to have incorrect VIN model year information and were excluded from the table. For those vehicles with a complete VIN code, the model year breakdown by manufacturer is presented in Table 5. The data was collected at a used truck lot, and at the time of collection no 2002 model year vehicles were in the used inventory surveyed for this project. The average model year was 1997.6.

Table 5 Manufacturer by Model Year distribution

	1993	1994	1995	1996	1997	1998	1999	2000	2001	Totals
CAT	0	1	2	5	4	5	4	15	0	36
CUMMINS	2	2	5	13	18	20	14	8	1	83
Detroit Diesel	0	0	9	7	12	16	11	2	1	58
Totals	2	3	16	25	34	41	29	25	2	177

Table 6 CAT Engine Model Distribution

	Count
3126B	11
3176B	4
3406C	1
3406E	45
C 10	4
C 12	7
Total	72

Table 7 Cummins Engine Model Distribution

	Count
ISB 190	4
ISB 195	5
ISM 330	2
M11-280E+	8
M11-310E	1
M11-330E	12
M11-330E+	12
M11-350E+	2
M11-370E	4
M11-400E+	13
M11-410E+	1
N14-350E	1
N14-370 ESP+	1
N14-370E	4
N14-370E+	9
N14-370ESP+	9
N14-410	1
N14-410E	5
N14-430E	1
N14-435E	1
N14-435E+	1
N14-435ESP+	1
N14-460E	1
N14-460E+	1
N14-475	3
STA-15	2
Total	105

Table 8 DDC Engine Model Distribution

	Count
6047GK60	1
6067BK60	7
6067GK60	42
6067GU60	1
6067MK60	1
6067PK60	8
6067SK60	5
6067TK60	13
6067WK60	3
6067WU60	3
Total	84

3.1.1 Analysis of Power Rating Data

Advertised Power was obtained from the data downloads. For vehicles that had multiple advertised power levels (330/450 hp for example) the lower power was used for the input value. With additional information this data field could likely be improved.

Table 9 Manufacturer by Advertised Power distribution

	CAT	CUMMINS	Detroit Diesel	Totals
190	10	4	0	14
195	0	5	0	5
251	1	0	0	1
280	0	8	0	8
310	0	2	0	2
315	0	0	1	1
325	1	0	0	1
330	0	25	0	25
335	3	0	0	3
350	3	11	3	17
355	4	0	0	4
365	0	0	8	8
370	1	29	5	35
375	1	0	0	1
380	3	0	0	3
400	0	11	9	20
410	4	0	0	4
425	1	0	1	2
429	1	0	0	1
430	0	1	31	32
434	10	0	0	10
435	2	2	0	4
451	1	0	0	1
455	2	0	0	2
460	0	5	0	5
470	0	0	10	10
475	15	0	0	15
500	4	0	22	26
550	3	0	0	3
600	2	0	0	2
Totals	72	103	90	265

In this data set, significant differences in average advertised power were found between the three manufacturers (Table 7 and Figure 4). On average, the Cummins vehicles had lower advertised power in this sample from the repair shop than the CAT and DDC vehicles. The average advertised power for the DDC vehicles were significantly higher than that of the CAT vehicles (Table 8) and both CAT and DDC were significantly higher than Cummins when tested using the Fishers PLSD means test.

Table 10 Manufacturers by Advertised Power ANOVA

ANOVA Table for Advertised Power

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Manufacturer	2	413185.453	206592.727	38.629	<.0001	77.258	1.000
Residual	262	1401212.524	5348.139				

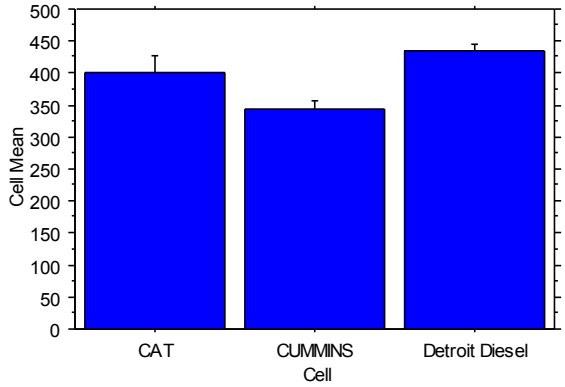

Figure 4 Manufacturers by Advertised Power Average with 95% Confidence Limits

Fishers PLSD Test is a conservative post hoc means test for ANOVA's that takes the significance level of the corresponding F-test into account. Mean pairs having significant differences are identified with an "S".

Table 11 Fishers PLSD Test of mean differences in Advertised Power

Fisher's PLSD for Advertised Power
Effect: Manufacturer
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
CAT, CUMMINS	57.124	22.120	<.0001	S
CAT, Detroit Diesel	-34.389	22.768	.0032	S
CUMMINS, Detroit Diesel	-91.512	20.778	<.0001	S

3.1.2 Analysis of Peak Torque Output (PTO) Data

In addition to Advertised Power, Peak Torque was obtained from the entire set of engine downloads. Peak Torque varied significantly from engine to engine, with low, medium, and high torque levels found in each manufacturer in the sample (Table 9).

Table 12 Manufacturer by Peak Torque distribution

Observed Frequencies for Peak Torque, Manufacturer

	CAT	CUMMINS	Detroit Diesel	Totals
520	10	9	0	19
660	1	0	0	1
1050	0	8	0	8
1150	0	1	1	2
1250	1	12	1	14
1251	1	0	0	1
1350	7	29	10	46
1400	0	3	0	3
1450	6	36	38	80
1452	2	0	0	2
1550	9	3	22	34
1600	1	0	0	1
1649	4	0	0	4
1650	15	2	18	35
1652	1	0	0	1
1750	9	0	0	9
1850	3	0	0	3
2050	2	0	0	2
Totals	72	103	90	265

Significant differences were found in peak torque between manufacturers with Cummins having somewhat lower average torque than CAT and DDC (Table 10, Figure 5).

Table 13 Manufacturer by Peak Torque ANOVA

ANOVA Table for Peak Torque

	DF	Sum of Squares	Mean Square	F-Value	P-Value	Lambda	Power
Manufacturer	2	2228927.212	1114463.606	14.137	<.0001	28.275	1.000
Residual	262	20653846.584	78831.476				

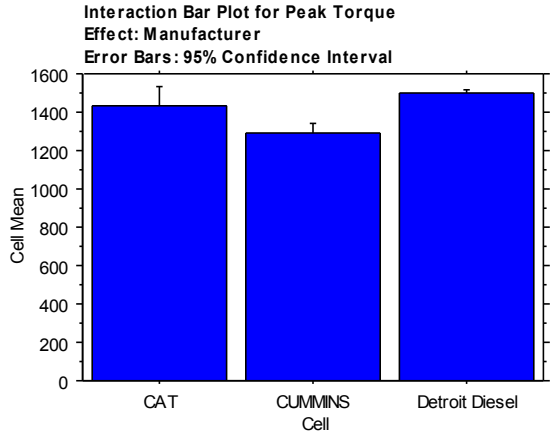

Figure 5 Manufacturers by Peak Torque Average with 95% Confidence Limits

Significant differences were found between the CAT and Cummins average peak torque and between the Detroit Diesel and the Cummins average peak torque, but CAT and Detroit Diesel did not have significant differences in peak torque (Table 11).

Table 14 Fishers PLSD Test of mean differences in Peak Torque

Fisher's PLSD for Peak Torque
Effect: Manufacturer
Significance Level: 5 %

	Mean Diff.	Crit. Diff.	P-Value	
CAT, CUMMINS	146.956	84.926	.0008	S
CAT, Detroit Diesel	-62.181	87.414	.1625	
CUMMINS, Detroit Diesel	-209.137	79.771	<.0001	S

Table 15 Summary of Vehicle Operating Characteristics

		Total Time (secs.)	Total Distance (miles)	Total Fuel Used (gallons)	Fuel Economy (mpg)	Total Idle Fuel (gals.)	Total Idle Time (secs)	% Time at Idle	Total PTO Fuel (gals.)	Total PTO Time (secs.)	% Time at PTO	Total Cruise Time (secs.)	% Time at Cruise	Total Brake Time (secs)	Ave Load Factor (% of max)	Ave Vehicle Speed (mph)	Max Vehicle Speed (mph)	Max Engine Speed (rpm)	Brake actuations /1000 miles
Fleet Total	Max	30264	1032566	160419	10.4	26444	20264	528.3	7912	12337	57.7	7029	46.1	1213	63	58	128	5342	3870
	Min	93	2889	621	3.6	0	0	0.0	0	0	0.0	130	1.2	11	3	0	0	1852	18
	N	244	244	244	244	243	243	243	240	242	243	84	84	76	49	52	57	57	95
	Ave	11562	366038	57424	6.6	1928	3720	35.3	725	1370	9.3	2670	18.4	325	43	29	92	2573	546
	SD	6638	205170	34326	1.1	2602	3832	50.4	1262	2322	13.6	1564	9.0	237	10	10	23	541	733
	COV	0.57	0.56	0.60	0.16	1.35	1.03	1.43	1.74	1.70	1.47	0.59	0.49	0.73	0.23	0.34	0.25	0.21	1.34
Detroit Diesel	Max	30264	859797	146210	7.6	26444	17475	64.9	4899	12118	45.1	7029	46.1	1213					
	Min	2893	59023	10716	4.0	209	536	4.3	2	3	0.0	130	1.2	11					
	N	86	86	86	86	85	85	85	84	85	85	84	84	76					
	Ave	14772	452889	71821	6.4	2672	6456	42.9	1366	2856	18.8	2670	18.4	325					
	SD	5900	165400	27780	0.6	2980	3858	13.6	1209	2534	13.3	1564	9.0	237					
	COV	0.40	0.37	0.39	0.09	1.12	0.60	0.32	0.89	0.89	0.71	0.59	0.49	0.73					
CAT	Max	29634	926059	160419	7.7	15313	20264	528.3	110	10	0.1				63	58	128	5342	
	Min	93	2889	621	3.9	0	0	0.0	0	0	0.0				3	0	0	1852	
	N	59	59	59	59	59	59	59	59	59	59				49	52	57	57	
	Ave	8161	279599	48328	6.1	2493	3477	57.5	2	0	0.0				43	29	92	2573	
	SD	8192	258400	45818	0.9	3091	4022	93.8	14	1	0.0				10	10	23	541	
	COV	1.00	0.92	0.95	0.15	1.24	1.16	1.63	6.17	4.55	4.70				0.23	0.34	0.25	0.21	
Cummins	Max	21363	1032566	156551	10.4	8274	7829	56	7912	12337	58								3870
	Min	1521	34799	3623	3.6	4	5	0.1	0	0	0.0								18
	N	99	99	99	99	99	99	99	97	98	99								95
	Ave	10802	342106	50337	7.2	953	1517	15.6	610	905	6.6								546
	SD	4770	171568	26969	1.2	1348	1580	12.7	1418	2130	12.9								733
	COV	0.44	0.50	0.54	0.17	1.41	1.04	0.82	2.32	2.35	1.96								1.34

3.2 Vehicle Operation: Fuel Economy, Activity Maps, Idle Time

The analysis in this section focuses on descriptive statistics for the vehicle operational characteristics. An overall view of the data is shown in Table 15, Summary of Vehicle Operating Characteristics. The data included are listed in the table below:

Total Time	PTO Fuel	Avg Load Factor
Total Distance	Total PTO Time	Avg Vehicle Speed
Total Fuel Used	% Time at PTO	Max Vehicle Speed
Total Fuel Economy		Max Engine Speed
	Total Cruise Time	Brake actuations/1000 miles
Total Idle Fuel	% Time at Cruise	
Total % Time at Idle		
Idle Time Total	Total Brake Time	

Table 16 Parameters included in the Summary of Operational Parameters

Data in Table 15 were analyzed by manufacturer and for the overall population. For example, the examination of the population data show that the distance traveled ranged from 2,889 to 1,032,566 miles and the overall average was 366,038 miles which are lower than most trucks would need for an in-frame overhaul. For these data, the standard deviation was 20,517 and the coefficient of variation was 0.56. Looking at the average mileage suggests that many of the trucks were in the shop for other than a major repair.

3.2.1 Analysis of Fuel Economy Data

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

Table 17 Descriptive Statistics for Calculated Fuel Economy

	calculated fuel economy
Mean	6.579
Std. Dev.	1.253
Std. Error	.078
Count	261
Minimum	.284
Maximum	10.419
# Missing	0

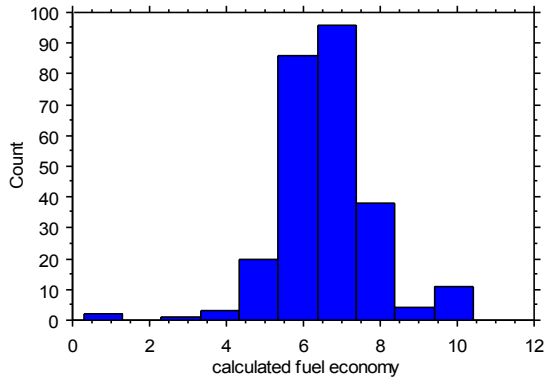

Figure 6 Histogram of Calculated Fuel Economy

Average calculated fuel economy varied from year to year within the vehicles sampled in this study (Table 17, Figure 6). The average was 6.6 miles per gallon, a value that seems quite reasonable. Note the standard deviation was 1.2 suggesting and the coefficient of variation was about 20%. These values are comparable to those measured by the CE-CERT Mobile Emission Laboratory during the cruise or freeway driving portion of the ARB's 4-Mode Driving cycle for heavy-duty vehicles (Cocker et al., 2004). The relative narrow distribution can be visualized in the histogram of Figure 6.

Table 18 Vehicle Count, Mean, Standard Deviation, Standard Error for Fuel Economy by Model Year

	Count	Mean	Std. Dev.	Std. Err.
1983	2	6.758	3.990	2.822
1993	2	5.618	.359	.254
1994	2	6.857	.758	.536
1995	16	6.184	.955	.239
1996	21	6.497	.753	.164
1997	34	7.321	.798	.137
1998	41	6.587	.654	.102
1999	29	6.681	1.821	.338
2000	25	7.246	1.445	.289
2001	2	6.011	.197	.139

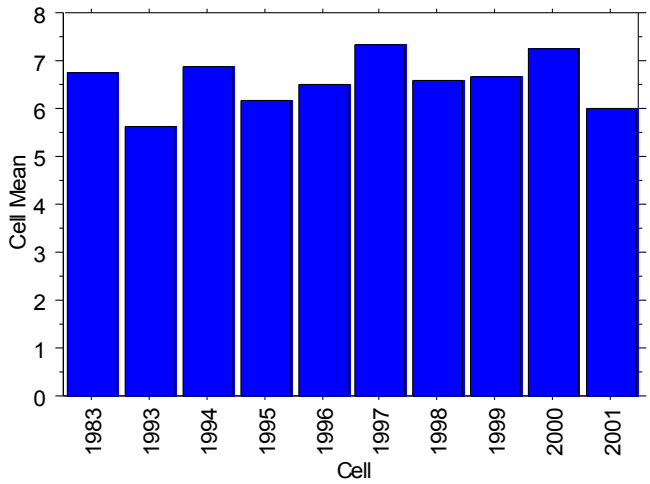

Figure 7 Average Calculated Fuel Economy by Model year

Fuel Economy from the engine download data sheets had occasional very large values that were obviously incorrect (over 100 mpg for example) so the Total Fuel Used and the Total Distance were used to calculate fuel economy as well. Some values of the calculated fuel economy were also obviously invalid and those vehicles were dropped from the analysis. The values had very good correlations for the majority of the vehicles (Figure 8), but were very different for a subset of vehicles, with a majority of the vehicles that had large discrepancies in the two fuel economy values having Total Fuel Economy = 0.

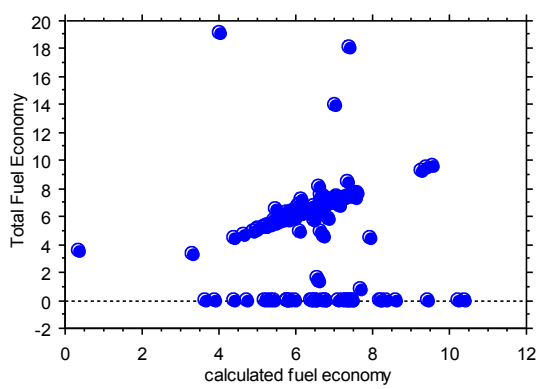

Figure 8 Plot of Data Download Fuel Economy vs. Calculated Fuel Economy

3.2.2 Analysis of Activity Data

For the CAT vehicles, activity data was available on the percentage of time that the vehicle was operated within (Vehicle Speed, mph)/(Engine Speed, rpm) bins. An example data set is provided in Table 19.

Table 19 Example CAT Vehicle Activity Data

	Engine Speed (rpm)																
Vehicle S	**0-599**	**600-699**	**700-799**	**800-899**	**900-999**	**1000-109**	**1100-119**	**1200-129**	**1300-139**	**1400-149**	**1500-159**	**1600-169**	**1700-179**	**1800-189**	**1900-199**	**2000-209**	**2100-219**
0-4	0.09	14.95	17.37	0.27	0.32	0.34	0.15	0.12	0.02	0.03	0.14	0.01	0	0	0	0	0
5-9	0	0.22	0.45	0.24	0.3	0.3	0.3	0.27	0.24	0.11	0.03	0	0	0	0	0	0
10-14	0	0.09	0.13	0.06	0.09	0.15	0.19	0.18	0.17	0.12	0.04	0.01	0	0	0	0	0
15-19	0	0.05	0.08	0.02	0.05	0.09	0.13	0.1	0.11	0.06	0.05	0.02	0	0	0	0	0
20-24	0	0.03	0.07	0.02	0.03	0.05	0.06	0.12	0.13	0.16	0.05	0.03	0.01	0	0	0	0
25-29	0	0.02	0.06	0.02	0.01	0.05	0.1	0.13	0.11	0.11	0.08	0.04	0.01	0	0	0	0
30-34	0	0.01	0.04	0.01	0.02	0.04	0.03	0.08	0.16	0.16	0.09	0.06	0.01	0	0	0	0
35-39	0	0	0.02	0.01	0.01	0.03	0.1	0.06	0.11	0.1	0.17	0.09	0.02	0.01	0	0	0
40-44	0	0	0.01	0	0.01	0.01	0.01	0.12	0.12	0.14	0.28	0.04	0.04	0.01	0	0	0
45-49	0	0	0	0	0	0.03	0.01	0.06	0.07	0.44	0.18	0.4	0.12	0	0	0	0
50-54	0	0	0	0	0	0	0.08	0.04	0.31	0.36	0.78	0.76	0.02	0.03	0	0	0
55-59	0	0	0	0	0	0	0	0.24	0.22	2.26	6.69	0.26	0.64	0.05	0	0	0
60-64	0	0	0	0	0	0	0	0	1.28	21.77	3.61	3.15	0.01	0.04	0	0	0
65-69	0	0	0	0	0	0	0	0	0	4.81	7-Jan	0.18	0.26	0.01	0	0	0
70-74	0	0	0	0	0	0	0	0	0	0	1.18	0.45	0	0	0	0	0
75-79	0	0	0	0	0	0	0	0	0	0	0	0.07	0.04	0	0	0	0
Total	0.09	15.37	18.23	0.65	0.84	1.09	1.16	1.52	3.05	30.63	20.44	5.57	1.18	0.15	0.00	0.00	0.00

In total there was activity data for forty five (45) CAT vehicles; ten (10) were CAT 3126B engines and thirty-five (35) were 3406E engines, Plots were constructed for the percentage of time that each engine spent at each speed /RPM point. Examination of the plots showed that twenty-five of the 3406E CAT vehicles showed only one significant high-speed operating region. Figure 9 is a plot of one typical single peak vehicle and the rest of the plots are shown in Appendix D. The surprising aspect of this result is the suggestion that there is no significant operating time at any other modes, including idle. Future research on this topic would be helpful in determining if this is an artifact of this data set, methodology, or an widespread characteristic within the on-road fleet.

The rest of 3406E CAT vehicles have two operating peaks, one (~50% of total time) is closer to the idling/low-driving region, and another (~45%) is located in the same as other 3406E vehicles' high-speed operating region (Figure 10). This difference in operating behaviors can be defined as vehicles operated under different traffic situations or perhaps another aspect of the data logging features that we do not understand. A discussion is needed with Caterpillar.

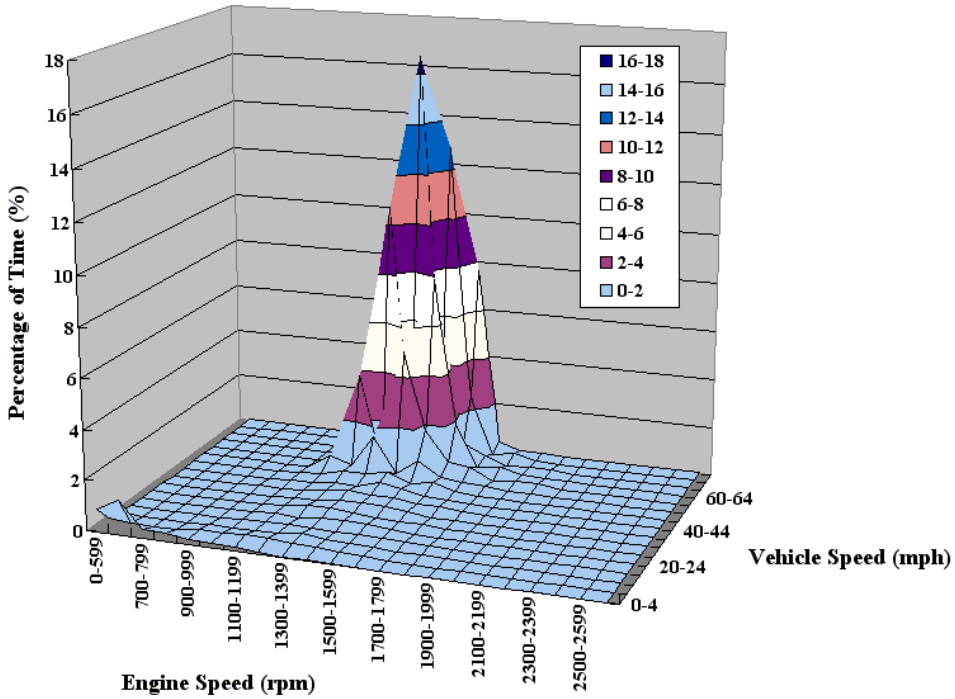

Figure 9 CAT 3046E Single peak activity plot

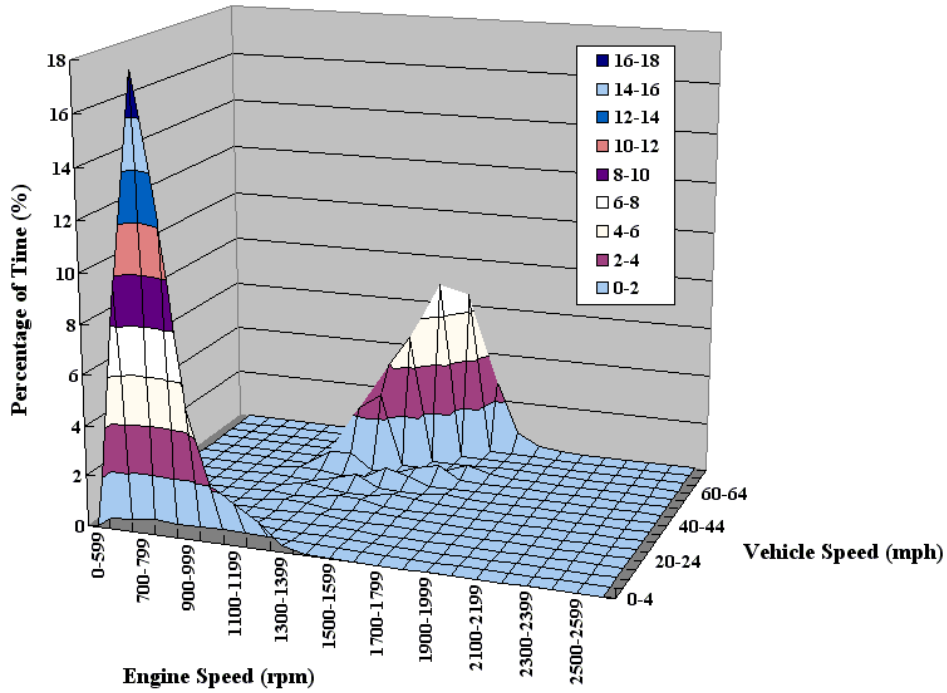

Figure 10 CAT 3046E two peak activity plot

As mentioned in the introduction to this section, ten of vehicles used a CAT 3126B and these engines exhibited a more distributed activity pattern (Low Power/Transient/High Power ratio =

40:45:15). These vehicles were have an engine with less power output and peak torque and are often used for intra-city operations. An example of this usage pattern is provided in Figure 11.

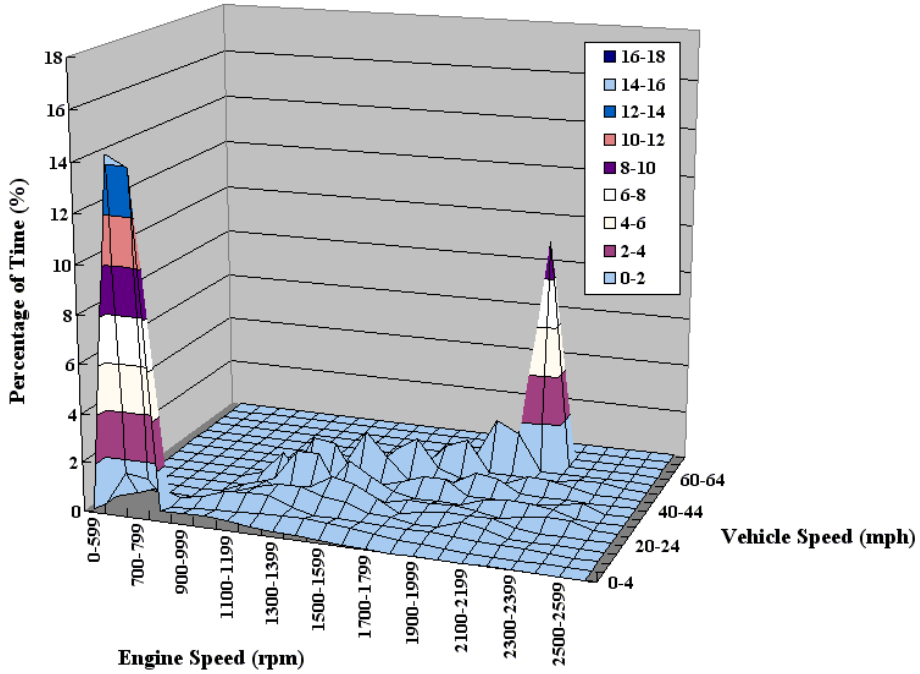

Figure 11 CAT 3126B activity plot

3.2.3 Analysis of Idle Data

Percent time at idle is an important factor in computing the contribution to inventory for HHDDTs. The idle time was calculated for all vehicles; however, some had missing data or values for idle time that exceeded 100% of the time. Thus data for 20 of the 270 vehicles were removed and the results for Idle Time (%) are presented in Table 20. The average idle time of 30±19% is comparable to the values previously reported (Battelle, 1999) and to the values currently used in EMFAC2000 (ARB, 2002).

Table 20 Percent Idle Time Descriptive Statistics

	% Time at Idle
Mean	30.491
Std. Dev.	19.214
Std. Error	1.215
Count	250
Minimum	0.000
Maximum	87.000
# Missing	0

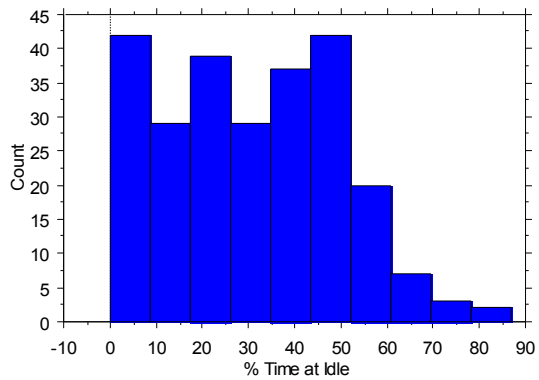

Figure 12 Histogram of Percent Time at Idle.

Percent Idle Time varied considerably from year to year (Table 21, Figure 13) with the newer vehicles showing the less amount of idle time.

Table 21 Count, Mean, Standard Deviation for Percent Idle Time by Model Year

	Count	Mean	Std. Dev.	Std. Err.
1980	1	0.000	•	•
1983	2	12.500	17.678	12.500
1993	1	0.000	•	•
1994	2	5.785	8.054	5.695
1995	15	38.834	10.400	2.685
1996	23	34.191	18.558	3.870
1997	34	26.918	16.874	2.894
1998	40	32.809	21.090	3.335
1999	28	29.233	19.669	3.717
2000	20	14.720	13.622	3.046
2001	2	31.000	12.728	9.000
2003	1	39.000	•	•
2004	1	16.100	•	•

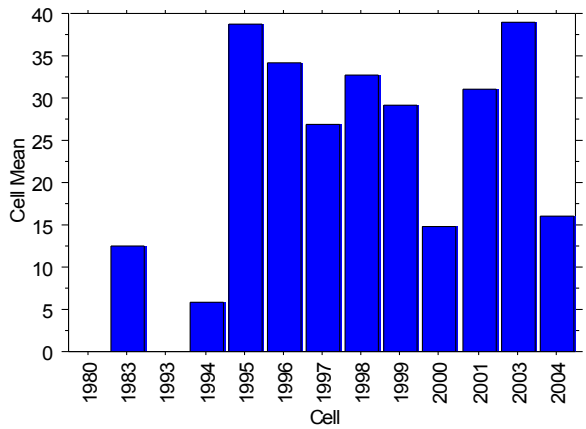

Figure 13 Percent Time at Idle by Model Year

3.3 Data Mining Trials

After loading the common variables data set into SAS (SAS Inc., 2004) SAS Enterprise Miner was used to identify predictor variables for Fuel Economy. Engine model indicator variables and rated horsepower were identified as significant predictors of fuel economy. A significant regression was found between rated horsepower and calculated fuel economy (Table 20), with higher horsepower leading to lower fuel economy.

Table 22 Regression summary table for Advertised Power vs. Calculated Fuel Economy

ANOVA Table
calculated fuel economy vs. Advertised Power
Inclusion criteria: Criteria 2 from combined file overlapping variables4.xls (imported).svd

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	106.515	106.515	81.419	<.0001
Residual	220	287.811	1.308		
Total	221	394.325			

Horsepower was found to explain 27% of the variability in fuel economy (Table 21), having an R-square of .27. This indicates that while the regression is significant, horsepower on its own does not explain the majority of the variability in fuel economy. Individual vehicle operation characteristics and unmeasured factors such as vehicle load will obviously have major influence as well.

Table 23 R-square, Adjusted R-square, and RMS Residual of Horsepower vs Calculated Fuel Economy Regression

Count	222
Num. Missing	3
R	.520
R Squared	.270
Adjusted R Squared	.267
RMS Residual	1.144

The regression plot is presented in Figure 14, showing the variability about the line as well as several questionable data points with very low fuel economy values.

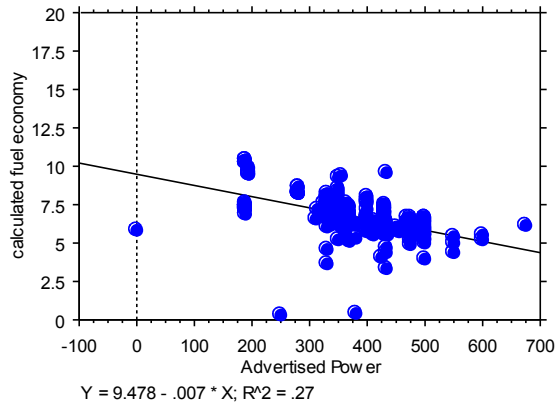

Figure 14 Plot of Rated Horsepower Regression vs. Calculated Fuel Economy

A significant regression was also found between Idle Time and Fuel Economy (Table 22).

Table 24 Regression summary table for Idle Time vs. Calculated Fuel Economy

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	35.053	35.053	21.802	<.0001
Residual	222	356.935	1.608		
Total	223	391.988			

Table 25 R-square, adjusted R-square, and RMS Residual of Idle Time vs. Calculated Fuel Economy Regression

Count	224
Num. Missing	1
R	.299
R Squared	.089
Adjusted R Squared	.085
RMS Residual	1.268

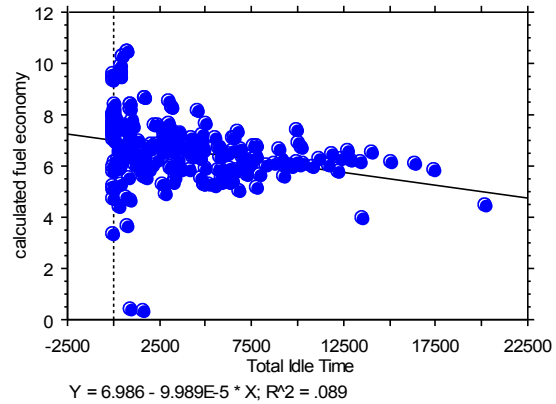

Figure 15 Plot of Idle Time Regression vs. Calculated Fuel Economy

4. Summary and Conclusions

Engine and operational data were entered into a database for the 270 vehicles used in this exploratory study. The unique feature of the data is that it was obtained from an independent repair shop as a download of the electronic chip. Putting the data into a form that could be easily subjected to computer analysis proved challenging, Manual data entry was necessary after automated OCR programs had difficulty with the faint printing and angled text on some of the data sheets. Initial data input for this project involved manual transcription of pdf files into MS Excel data files for each manufacturer. For the general data fields, a MS Access program was used for data entry, with the data output as MS Excel files. For the activity data the pdf files were input directly into the Excel files. Forty-five vehicles were entered into the database with detailed activity data.

The data was loaded into a SAS Enterprise Miner data-mining database for analysis of relationships within the database. Descriptive statistics and basic statistical analysis were carried out using StatView software by SAS Institute and basic characterization of the 270 vehicle fleet was completed. The data mining tools identified engine horsepower and specific engine model as significant factors in predicting fuel economy. The idle time and fuel economy results were comparable with those measured over the road and in previous studies. A significant relationship was also found between percent idle time and average fuel economy.

This study has shown that sampling the on-road heavy-duty vehicle fleet using engine downloads can be a cost effective way of obtaining in-use data on vehicle fleet characteristics as well as operational behavior. While not providing the second-by-second time resolution provided by a data logger, it does provide macro activity data at a low cost of collection and analysis.

Further analysis is recommended, especially of the sub populations of these data to determine if the subset is representative of on-road fleets in California, and if so, whether the activity data agree with other studies. Of immediate interest would be the values found for the time spent at idle. Another interesting probe would be the relationship between the measured activity profiles and the weighted activities assumed for the engine certification tests.

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Appendix A. DDC Data

Vehicle #	Engine Model	VIN	Engine Serial Number	ECM Serial Number	Advertised Power	Governed Speed	Peak Torque	RPM at Peak Torque	Total Time	Total Distance	Total Fuel Used	Total Fuel Economy	Total Idle Fuel	Total Idle Time	% Time at Idle	Total PTO Fuel	Total PTO Time	% Time at PTO	Total Brake Time	Total Cruise Time	% Time at Cruise
1	6067BK60	1FUJA6CG71LH69877	06R0606777	VH600VM8	500	2110	1650	1200	4296.5	155575.1	25294.4	6.2	1347.3	1730.2	40	1146.4	1353.2	31	37.7	584.8	14
2*	6067BK60		06R0553861	VH602KFO	500	2110	1650	1200	54.6	2619.8	518.8	5.0	6.0	13.9	25	0.8	1.1	2	1.4	1.3	2
3	6067BK60	1FUYSSZB8YLA17972	06R0535433	VF603LZU	500	2110	1650	1200	6623.6	291718.5	45082.6	6.5	820.8	1755.3	27	56.8	77.0	1	458.3	1065.8	16
4			06R0507198		500	2110	1650	1200	8089.1	268726.8	45978.6	5.8	1587.4	3120.2	39	1088.9	1986.8	25	223.3	2386.7	30
5	6067BK60		06R0500752	VH601FHZ	500	2110	1650	1200	5097.8	141574.8	26909.9	5.3	1319.6	2694.9	53	860.1	1274.1	25	60.0	685.3	13
6	6067BK60	476273D	06R0500751	VF602VL8	500	2110	1650	1200	14129.0	345265.5	61488.1	5.6	2926.0	8031.8	57	826.5	1552.8	11	52.8	2041.1	14
7	6067BK60	1FUYSSZBXYPA91578	06R0494008	VF602NNV	500	2110	1650	1200	12952.2	392815.6	66570.0	5.9	2577.4	6312.3	49	275.5	504.3	4	170.8	3306.9	26
8	6067MK60	XPA16761	06R0481092	VF602B4J	430	1810	1550	1200	11468.2	383924.5	65409.1	5.9	3301.9	5028.3	44	2639.5	3285.3	29	347.9	3217.6	28
9	6067BK60	1FUPCSZB5XPA09331	06R0477664	VF6027VF	500	2110	1650	1200	6236.0	293603.3	49409.3	5.9	1386.8	3144.4	38	692.5	1795.0	29	123.0	2389.3	38
10	6067TK60	1FUYSSEB1XL759034	06R0461741	VF601X4Z	430	2110	1450	1200	11096.9	483014.3	69605.6	6.9	1137.8	2990.3	27	369.0	489.5	4	136.8	2367.4	21
11	6067TK60	814915J	06R0461709	VF601V3B	370	1810	1450	1200	15335.5	721157.9	97098.4	7.4	1421.3	3149.2	21	1158.9	2407.9	16	450.3	3068.2	20
12	6067PK60	1FUPCSZB7XLA10020	06R0460434	VF601V68	500	2110	1650	1200	10669.8	369224.2	56675.6	6.5	1612.6	4219.6	40	782.8	1778.6	17	330.3	1012.5	9
13	6067TK60	1FUYSSEB6XL759028	06R0460365	VF601VKU	430	2110	1450	1200	12450.0	412102.0	66621.0	6.2	1714.1	536.0	43	203.9	450.5	4	393.7	2741.1	22
14	6067TK60	814909J	06R0459230	VF601ULW	370	1810	1450	1200	13832.8	656379.4	93018.4	7.1	1586.4	2754.9	20	1370.3	2199.4	16	404.3	2837.3	21
15	6067TK60	1FUYSSEB2XPA12084	06R0443022	VF601EQ9	470	1810	1550	1200	15869.1	517166.1	88296.1	5.9	4739.1	7339.0	46	3819.9	4465.2	28	387.7	2207.2	14
16	6067TK60	1FVNBSEB3XLA09023	06R0441005	VF601D5C	470	2110	1550	1200	7606.4	319313.2	53485.5	6.0	553.1	1273.3	17	261.5	452.1	6	337.2	1817.1	24
17	6067TK60		06R0440868	VF601D72	370	1810	1450	1200	13119.0	582185.7	87612.1	6.6	779.3	2135.9	16	60.1	118.9	1	0.0	4964.5	38
18	6067TK60		06R0440350	VF601BYN	370	1810	1450	1200	12859.5	543801.4	80050.0	6.8	827.5	2342.8	18	56.4	106.9	1	0.0	4565.6	36
19	6067TK60		06R0440104	VF601CCT	370	1810	1450	1200	12110.2	539173.7	81521.0	6.6	717.1	1974.0	16	57.5	106.1	1	0.0	4823.0	40
20	6067PK60	464353D	06R0429221	VF601RCY	500	2110	1650	1200	14227.7	467256.2	84397.3	5.5	2477.3	6339.8	45	2258.8	5943.8	42	194.4	3132.7	22
21	6067TK60	1FUYSSEB2XPA18922	06R0428294	VF600XWM	430	1810	1550	1200	14287.2	592651.1	81843.6	7.2	1729.8	3655.5	26	1131.1	1575.2	11	614.3	2425.1	17
22	6067PK60	1FUYSSZB9XL991729	06R0420819	VF600XQ6	500	2110	1650	1200	12957.3	423426.7	63492.6	6.7	26443.6	5872.3	45	1806.9	3067.9	24	213.1	2060.1	16
23	6067PK60	1FUYSSZB0XLA10433	06R0417258	VF600UKL	500	2110	1650	1200	9597.8	392516.6	60589.4	6.5	1089.6	2919.6	30	513.4	1289.3	13	127.7	1340.9	14
24	6067PK60	1FUPCSZB8XPA16370	06R0416979	VF600TDS	500	2110	1650	1200	15248.4	731218.7	109797.6	6.7	700.4	1850.9	12	308.1	470.2	3	401.6	7029.4	46
25	6067PK60	1FUYSSZB4WP975171	06R0406634	VF600K1Y	500	2110	1650	1200	16310.7	456610.4	75566.9	6.0	2775.8	8776.3	54	493.5	1042.3	6	463.1	966.2	6
26	6067PK60	1FUPCSZB1XLA17187	06R044760	VF601JLR	500	2110	1650	1200	11723.5	355251.6	67062.4	5.3	3022.6	5932.7	51	1987.0	2593.9	22	133.1	562.5	5
27			06R0420008		500	2110	1650	1200	12788.9	331343.3	58859.3	5.6	2598.5	7280.1	57	1870.8	4787.4	37	308.9	1661.9	13
28	6067PK60	1FUYSSZB2WP975170	06R0407015	VF600L0M	500	2110	1650	1200	13026.6	445576.7	78802.9	5.7	2016.1	5983.5	46	557.5	1280.8	10	356.8	1373.9	11
29	6067TK60		06R0396355	VF6009CC	470	1810	1550	1200	19484.8	591317.0	99881.9	5.9	4379.0	9377.2	48	3125.0	4292.2	22	360.4	4716.6	24
30	6067TK60		06R0396354	VH601MDN	470	1810	1550	1200	3266.1	87899.6	14138.5	6.2	474.0	1710.8	52	102.9	141.1	4	59.1	406.4	12
31	6067TK60		06R0395903	VF6006NN	430	1810	1550	1200	11064.8	341760.8	51986.9	6.6	2379.9	4957.8	45	2073.3	3953.6	36	186.6	2502.3	23
32	6067GK60	1FUYDSEB0WP914903	06R0381503	SH6006A7	430	2110	1450	1200	22560.2	467079.3	71832.6	6.5	3755.3	14059.5	62	2026.1	4684.3	21	193.5	2377.3	11
33	6067GK60	1FUPCSZB2WP947538	06R0381405	VF600391	500	2110	1550	1200	16049.0	506482.1	84209.9	6.0	2773.6	7115.8	44	1546.5	3010.6	19	482.6	1788.2	11
34	6067GK60		06R0379590	SH60055B	430	1810	1550	1200	11878.0	385808.2	55694.8	6.9	1341.4	4894.8	41	1120.6	3756.6	32	203.2	3076.2	26
35	6067GK60		06R0379295	SH600079	430	1810	1550	1200	12269.9	373909.8	53127.3	7.0	1269.4	5537.1	45	1032.6	4400.1	36	188.4	3282.5	27
36			06R037142		430	1810	1550	1200	22272.8	568138.1	86342.5	6.6	3144.6	12735.4	57	2492.1	3644.8	16	660.6	1683.8	8
37	6067SK60	4VAWBBRF2WN751394	06R0370153	SG601L72	365	1810	1350	1200	20284.1	542197.6	86722.0	6.3	5952.1	11206.0	55	4899.4	8807.0	43	308.8	4010.7	20
38			06R0369752		430	1810	1550	1200	13887.8	551915.3	89796.1	6.1	2870.5	7571.8	45	2356.3	5756.3	41	314.0	3614.5	26
39	6067SK60	4VAWBBRF9WN751392	06R0369701	SG601GXB	365	1810	1350	1200	20110.8	588182.1	96567.9	6.1	3337.0	10378.4	52	458.0	1371.8	7	482.8	848.8	4

40	6067GK60	1FUYDSEB6WP913903	06R0368402	SG601DT7	430	2110	1450	1200	23252.8	456197.0	74399.4	6.1	5121.3	15083.2	65	3544.1	7002.4	30	283.3	3525.2	15
41	6067GK60	1FUYSSEBXWL893846	06R0367744	SG601JQQ	430	1810	1450	1200	21144.0	474329.2	76102.1	6.2	5379.9	12410.7	59	4668.0	9344.7	44	325.8	5087.5	24
42	6067GK60	1FUYSSEB8WL893845	06R0367432	SG601HHB	430	1810	1450	1200	19256.8	399666.8	62016.0	6.4	4327.8	11906.4	62	3072.0	5968.3	31	226.2	3401.3	18
43	6067GK60	1FUYDSEB3WP892721	06R0365839	SG601GL8	430	2110	1450	1200	25464.3	489972.7	81187.3	6.0	5588.3	16384.8	64	3415.1	6004.0	24	477.1	3447.6	14
44	6067GK60	4VG7DARH4WN749405	06R0364141	SG601FR3	470	1810	1550	1200	16530.6	506482.5	80923.1	6.3	3822.6	7659.4	46	3645.8	7077.2	43	487.5	4580.2	28
45	6067GK60	1FUYSSEB1WL893802	06R0358697	SG6016K7	430	1810	1450	1200	16360.0	393802.5	63504.4	6.2	3706.5	9180.8	56	2332.3	3578.8	22	275.3	2706.7	17
46	6067SK60	760169J	06R0357753	SG6018E0	365	1810	1350	1200	8927.3	233190.0	43919.3	5.3	1527.6	3292.4	37	26.8	58.5	1		1015.5	11
47	6067GK60	748406J	06R0352543	SG60148U	470	2110	1550	1200	22306.8	721531.9	121909.6	5.9	2484.5	10875.3	49	418.9	1076.7	5	418.5	5303.1	24
48	6067GK60	748402J	06R0351700	SG600T23	470	2110	1550	1200	24512.0	684092.0	111555.6	6.1	3435.4	13440.9	55	1452.0	3631.6	15	367.8	4068.3	17
49	6067GK60	1FUYDZYB1WP725469	06R0350183	SG6011G6	430	1810	1450	1200	13367.5	488092.1	68946.6	7.1	1624.4	4243.5	32	1261.5	3071.0	23	204.7	4924.3	37
50	6067GK60	1FUYDZYBXWP725468	06R0350179	SG600WUE	430	1810	1450	1200	16665.4	509230.8	69701.3	7.3	2291.6	6817.0	41	1824.3	5050.9	30	330.8	3303.7	20
51	6067GK60	1FUPCSZB7WP806836	06R0347824	SG600YJW	500	2110	1650	1200	18194.7	605608.3	95905.8	6.3	2574.5	7067.0	39	1271.4	2266.4	12	570.7	3348.3	18
52	6067GK60	1FUYSSEB1WL730129	06R0345596	SG600WGG	430	1810	1450	1200	15682.8	550043.1	83907.9	6.6	2464.0	6491.5	41	1377.5	2126.9	14		2931.4	19
53	6067GK60		06R0340143	SG600R2F	430	1810	1550	1200	7263.9	169242.5	26085.1	6.5	928.0	4258.7	59	242.9	654.6	9	110.0	1353.2	19
54	6067GK60	1FUYSSEB8VL826726	06R0339948	SG600PC3	430	1810	1550	1200	17356.3	410656.3	59903.4	6.9	3290.9	10076.0	58	2056.1	4603.9	27	239.1	3564.5	21
55	6067GK60	1FUYSSEB9VL826721	06R0338767	SG600NUF	430	1810	1550	1200	14223.0	426297.4	60155.3	7.1	1616.6	6528.7	46	312.8	675.3	5	143.3	166.4	1
56	6067GK60	1FUYSSEB8VL836639	06R0323110	SG60078E	430	1810	1550	1200	18381.9	449955.6	60859.5	7.4	2253.6	10016.3	54	546.8	1327.5	7	235.2	3162.3	17
57	6067GK60	1FUPDSZB5VP729315	06R0325015	SG6009LJ	500	2110	1550	1200	18945.3	778801.3	124943.9	6.2	3718.5	4770.4	25	2201.3	2655.1	14	1045.6	4636.8	24
58	6067GK60	1FUYDZYB7VL549680	06R0319613	SG600361	400	1810	1450	1200	18678.0	472529.1	70647.0	6.7	3036.6	10225.3	55	1670.6	3415.8	18		2692.9	14
59	6067GK60	1FUPCSZB1VP729492	06R0314891	SF6007HV	500	2110	1550	1200	30263.5	669321.3	114692.5	5.8	8066.6	17474.6	56	4743.6	12117.6	40	304.9	688.0	2
60	6067GK60	1FUWDZYB1VP852115	06R0314164	SF60066E	430	1810	1450	1200	8134.4	274308.2	36342.1	7.5	697.4	2257.2	28	34.8	75.1	1	62.7	1210.8	15
61	6067GK60	1FUWDZYB7VL757582	06R0310666	SF6002SC	430	1810	1450	1200	11375.0	450463.2	67386.4	6.7	1210.8	3422.6	30	464.0	836.9	7	415.7	2392.8	21
62	6067GK60	1FUWDZYB3VL757580	06R0310658	SF6002RK	430	1810	1450	1200	10502.2	395485.3	59171.3	6.7	1114.0	3638.4	35	534.6	1202.5	11	112.4	2447.2	23
63	6067GK60	1FUWDZYB9VL757583	06R0310662	SF6002SE	430	1810	1450	1200	11603.5	439295.4	65870.5	6.7	1591.9	3970.6	34	1358.3	3377.1	29	300.6	1073.8	9
64	6067GK60	1FUYDZYB7VH781957	06R0292745		400	1810	1450	1200	13377.0	473385.0	66050.8	7.2	1165.6	4840.1	36	592.1	2308.9	17	34.0	2879.6	22
65	6067SK60	1FUWDCXA5TL657953	06R0284255	SE60054V	350	1810	1350	1200	9467.5	185759.6	28065.4	6.6	2518.5	4940.6	52	257.6	415.3	4	41.5	936.8	10
66	6067GK60	1FUYDZYB8TP719342	06R0287363	SE600AA7	470	2110	1450	1200	22003.1	491242.7	79357.0	6.2	2952.8	12916.0	59	1956.6	7216.8	33	469.1	2133.8	10
67	6067SK60	1FUWDCXA3TL657952	06R0283702	SE6007JR	350	1810	1350	1200	11199.0	304635.6	45324.4	6.7	2159.1	4601.1	41	345.1	576.5	5	99.8	2311.4	21
68	6067GK60	1FUYDZYB3TP719331	06R0272133	SC600LKR	470	2110	1450	1200	18768.6	514409.3	77724.8	6.6	2355.1	9043.5	48	1807.4	6730.9	36	536.3	1769.3	9
69	6067GK60	1FUYDZYB0TL598894	06R0262857	SC600CNF	400	1810	1450	1200	16158.7	420606.2	66467.9	6.3	1834.5	7793.9	48	224.6	688.9	4	253.6	567.7	4
70	6067WK60	1FUWDCXA7TL811675	06R0257935	SC6008FG	365	1810	1350	1200	12056.9	347262.8	45669.4	7.6	2843.8	5082.3	42	900.4	1604.4	13	311.3	985.4	8
71	6067GK60	2HSFHAMRXTC076864	06R0250167	SB600DB1	430	1810	1450	1200	10957.4	401316.6	61834.9	6.5	800	2800.7	26	34	77.1	1	447.6	1722	16
72	6067GK60	1FUYDZYBXSH601706	06R0233592	SA620R23	400	1810	1450	1200	14257.4	489959.6	72979.5	6.7	2013.8	5724.9	40	1590.6	4038.8	28	226.9	4046.6	28
73	6067GK60	1FUYDZYB8SH601705	06R0233571	SA620R20	430	1810	1450	1200	13419.4	415239	63165.6	6.6	1774.3	5897.3	44	1011.8	2828.6	21	186.4	2963.9	22
74	6067GK60	1FUYDZYB2SH601716	06R0233578	SA620R45	400	1810	1450	1200	21325.7	640730.5	104929.1	6.1	4830.3	9978.7	47	4223.8	8093.5	38	243.9	6358.2	30
75	6067GK60	1FUPDZYB3SH588423	06R0229519	SA6104GL	430	1810	1450	1200	21454.9	667291	112299.4	5.9	2089.6	9744.9	45	339.4	781	4	900.7	4883.4	23
76	6067GK60	1FUYDSEBXSP735522	06R0220665	SA620EUN	430	1810	1450	1200	21059.6	712279.8	105580.4	6.7	1906.9	7645.4	36	544.8	1435	7	1213.2	2355.3	11
77	6067GK60		06R0197512	SA60GCC1	400	1810	1450	1200	8921.2	255305.9	44096.1	5.8	1135.9	4213.3	47	892.5	3019.4	34	48.8	2128.3	24
78	6067WK60	4V1JBARF9SR836854	06R0196705	SA60BFR1	350	1810	1250	1200	13489	322138.7	45630.1	7.1	3998.5	6628.9	49	720.4	917.6	7		2369.9	18
79	6067GK60	1FUYBZY7SL542472	06R0196465	SE600NJH	400	1810	1450	1200	27772.3	859797.2	143789.8	6.0	4116.5	11723	42	1827.5	5470.8	20	922.7	5687.1	20
80	6067GK60	1FUYBZYB6SL542477	06R0196426	SA60BE31	400	1810	1450	1200	27007.6	759639.4	132652.5	5.7	4236	12297.8	46	2997.4	8100	30	609.2	5687.1	21
81					430	2110	1450	1200	13476.6	392802.1	71723.3	5.5	2200.5	5940.6	44	1637.5	4432.1	33	111.1	855.3	6
82	6067GK60	SO608392D	06R0185521	D101PHL1	470	1810	1550	1200	19186	773263.1	121566.6	6.4	790.8	1730.9	9		2443.3	13	827.3	5233.1	27
83	6067WK60		06R0181701	CH8005KQ	365	1810	1350	1200	2893.3	59023	10715.8	5.5	1263.8	1810.3	63	847	1143.1	40	10.7	406.5	14
84	6067WU60		06R0154395	11553686	675	1810	1350	1200	3002.4	155575.1	25294.4	6.2	1347.3	1730	40	1146	1353	45			0
85			06R0133806	01487662	425	1810	1450	1200	28800.5	591317	146209.5	4.0						0			0

86*	6067GU60		06R0119928	01469391	790	1810	1450	1200	24150.3		126913.8											
87*	6067WU60		06R0114692	01460263	365	1810	1350	1200	15568		73535.3											
88*	6067WU60		06R0114690	01460274	365	1810	1350	1200	15214.7		79363.1											
89	6047GK60	1FUY8HCB6VL839169	04R0015673	SE600U0N	315	2110	1150	1200	8748.9	208938.7	29160	7.2	208.8	3677.2	42	2	2.9	0		129.8	1
90	6067GK60	1FUYDZYB7SH601713	06RE002857	SA620970	400	1810	1450	1200	16029.9	440640.3	65453.5	6.7	1833.1	7802.7	49	462.6	1625.8	10	98.2	1871.9	12

*: Outlier vehicles

Appendix B. Cummins Data

Vehicle #	Engine Model	VIN	Engine Serial Number	ECM Serial Number	Advertised Power	Governed Speed	Peak Torque	RPM at Peak Torque	Total Time	Total Distance	Total Fuel Used	Total Fuel Economy	Total Idle Fuel	Total Idle Time	% Time at Idle	Total PTO Fuel	Total PTO Time	% Time at PTO	Brake actuations /1000 miles
1	ISM 330	1FUWDMCA2YLF13735	34952714	11007777	330	1800	1350	1200	5186.4	129929.7	19072.4	6.8	434.3	916.7	18	996.4	1901.6	36.7	494
2	M11-330E	1FUKBMCA7TL570278	34786633	144209	330	1800	12 1250	1200	10770	348593.5	46352.8	7.5	327.4	746	7	355.6	530	4.9	41
3	STA-15	1FUJCLBGX1PG03145	14012949	26003570					1521.3	61473.52	10468.3	5.9	273.6	326.5	21	93.4	91.1	6.0	262
4	ISB 190	1FV3GFAC3XHA54657	56543341	4029973	190	2600	520	1400	1716.4	38056.83	3719.9	10.2	228	497.7	29	1.9	4	0	2354
5	ISB 190	1FV3GFACHA54658	56541583	4031932	190	2600	520	1400	2865.2	72871.41	6994.4	10.4	291.3	784.9	27		0.1	0	1790
6	ISB 195	1FV3GFACXYHG31248	56611791	1012278	195	2500	520	1600	1835.8	39161.31	4141	9.5	322.9	485.6	26	3.1	7.7	0	2274
7	M11-280E+	1FUW3MCA7VL830759	34850027	3044354	280	1800	1050	1200	7679	232571.6	26927.4	8.6	790.5	1770	23	181.3	192.4	3	282
8	M11-280E+	1FUW3MCAXVL830755	34850026	3044357	280	1800	1050	1200	7814.3	251545.9	30003.9	8.4	335.8	935.6	12	118.6	132.6	2	497
9	M11-280E+	1FUW3MCA5VL830758	34850198	3043142	280	1800	1050	1200	8445.7	237010.9	28856	8.2	401.8	995.7	12	152.9	196.8	2	842
10	M11-280E+	1FUW3MCA1VL830756	34850202	3043825	280	1800	1050	1200	11187.5	363038.4	44041.1	8.2	1338.8	3207.2	29	76	84.7	1	181
11	M11-330E+	1FUWDMCA6XL990759	34908253	28038	330	1800	1350	1200	8229.6	274790.6	34613.8	7.9	4.9	7.6	0	0.8	0.8	0	2264
12	ISM 330	1FUWDMCA2YLF13735	34952714	11007777	330	1800	1350	1200	5186.4	129929.7	19072.4	6.8	434.3	916.7	18	996.4	1901.6	37	
13*	STA-15	1FUJCLBJX1PG03145	14012949	26003570					1521.3	61473.52	10468.3	5.9	273.6	326.5	21	93.4	91.1	6	37034
14	ISB 190	1FV3GFAC3XHA54657	56543341	4029973	190	2600	520	1400	1716.4	38061.41	3719.9	10.2	228	497.7	29	1.9	4	0	
15	ISB 190	1FV3GFAC5XHA54658	56541583	4031932	190	2600	520	1400	2865.2	72871.41	6994.4	10.4	291.3	784.9	27	0	0.1	0	1790
16	ISB 195	1FV3GFAC8YHG31250	56612329	1014929	195	2500	520	1600	1635.8	36474.06	3768.4	9.7	288.1	413.1	25	1	1.9	0	2556
17	ISB 195	1FV3GFAC8YHG31278	56612610	1014943	195	2500	520	1600	1740.3	34799.06	3623.3	9.6	315.4	478.6	28	2.4	5.3	0	3870
18	ISB 195	1FV3GFAC5YHG31240	56610776	1012661	195	2500	520	1600	1819.6	40928.59	4133	9.9	310.4	454.6	25	3.9	7	0	2181
19	ISB 195	1FV3GFACXYHG31248	56611791	1017228	195	2500	520	1600	1835.8	39161.31	4141	9.5	322.9	485.6	26	3.1	7.7	0	2274
20	M11-280E+	1FUW3MCA7VL830759	34850027	3044354	280	1800	1050	1200	7679	232571.6	26927.4	8.6	790.5	1770	23	181.3	192.4	3	282
21	M11-280E+	1FUW3MCAXVL830755	34850026	3044357	280	1800	1050	1200	7814.3	251545.9	30003.9	8.4	335.8	935.6	12	118.6	132.6	2	497
22	M11-280E+	1FUW3MCA5VL830758	34850198	3043142	280	1800	1050	1200	8445.7	237010.9	28856	8.2	401.8	995.7	12	152.9	196.8	2	842
23	M11-280E+	1FUW3MCA1VL830756	34850202	3043825	280	1800	1050	1200	11187.5	363038.4	44041.1	8.2	1338.8	3207.2	29	76	84.7	1	181
24	M11-310E	1FUKBMCA5SL508408	34771707		310	1800	1150	1200	17511.1	495121	75824.9	6.5	217.6	569.9	3	245	1730.8	10	408
25*	M11-330E	1FUKBMCA7TL570278	34786633	144209	330	1800	1250	1200	10769.9	348593.5	5811.9	60.0	327.4	746.1	7	355.6		0	41
26	M11-330E	1FUKBMCA2SL508401	34771248	128077	330	1800	1250	1200	16800.7	343694.7	74304.5	4.6	461.6	929.6	6	213.6		0	523
27	M11-330E	1FUKBMCA2SL508396	34771246	218110	330	1800	1250	1200	18935.6	468418.5	71740	6.5	118	462.1	2	104.1	238.8	1	571
28	M11-330E	1FUKBMCA6SL508398	34770787	713276	330	1800	1250	1200	14380.5	220560.5	60451.6	3.6	350.4	836.1	6	95.9	146.4	1	981
29*									15060.2	310262.8	65211.4	4.8	395.3	680.1	5	162.9	214.2	1	3
30*									17883.8	608189.5	2789.9	218.0	658	1341.7	8	447.1	595.1	3	284
31	M11-330E	1FUKBMCA5TL552703	34783057	139378	330	1800	1350	1200											
32	M11-330E	1FUKBMCA3YL570276	34786052	143279	330	1800	1250	1200	15681.9	438579	59249.5	7.4	142.4	314.1	2	81.6	140.9	1	833
33	M11-330E		34786503	143275	330	1800	1250	1200	15653.4	491997.7	67280.3	7.3	318.8	795.3	5	1034.1	1722.3	11	419
34	M11-330E	1FUKBMCAXTL570260	34786632	144206	330	1800	1250	1200											
35	M11-330E	1FUKBMCA4TL570271	34786051	143281	330	1800	1250	1200	17856.3	491363.8	65579.8	7.5	481.8	1136.1	6	797.1	1512.4	8	18
36	M11-330E	1FUKBMCA2TL570270	34786048	143331	330	1800	1250	1200	15993	432802.6	63632.9	6.8	1629.6	3405.1	21	222.5	455.3	3	111
37	M11-330E	1FUKBMCA1TL570275	34786046	143313	330	1800	1250	1200											
38									15213.1	439420.4	61707.1	7.1	334.5	933.6	6	467.8	900.6	6	241
39	M11-330E+	2HSFMAHR8VC023945	34820583	2035665	330	1800	1350	1200	17416.1	509568.1	76977.6	6.6	1313.9	2784.3	16	3752.4	5648.4	32	129
40	M11-330E+	1FUKBMCA2VL759780	34841943	3032440	330	1800	1350	1200	10839.4	332095.3	41273.9	8.0	45.8	102.8	1	242.4	364.9	3	547

41	M11-330E+	1FUW3MCA2WL967013	34902111	17597	330	1800	1350	1200	9925	304333.6	39229.5	7.8	55.1	125.5	1	334.8	419.2	4	520
42	M11-330E+	1FUW3MCA0WL967009	34901815	15926	330	1800	1350	1200	8316.9	264960.3	34693.6	7.6	26.1	60.9	1	260.3	483.5	6	321
43	M11-330E+	1FUW3MCA9WL967011	34902112	16445	330	1800	1350	1200	9522.7	311180.1	37955.6	8.2	20.5	62	1	71.9	126.9	1	364
44	M11-330E+	1FUWDMCA4XL990758	34908252	28028	330	1800	1350	1200	7136.7	205957.3	27045.4	7.6	1451.5	3032	42	44.5	69.2	1	318
45	M11-330E+	1FUWDMCA6XL990759	34908253	28038	330	1800	1350	1200	8229.6	274790.6	34613.8	7.9	4.9	7.6	0	0.8	0.8	0	2264
46	M11-330E+	1FU5BMCB5TL877311	34812495	2023505	330	1800	1350	1200	13924.3	586583.5	88334.4	6.6	327.5	874.7	6	596.1	1028.6	7	137
47	M11-330E+	1FUYDMCB9TP691013	34805606	3096662	330	1800	1350	1200	14977.1	491422.9	81581.9	6.0	875.9	2144.6	14	214.4	301.2	2	133
48	M11-330E+	1FUYDMCB2TP691015	34805603	2012510	330	1800	1350	1200	15889.3	569062.1	84239.1	6.8	331.8	903.3	6	48.5	73.7	0	324
49	M11-330E+	1FUWDMDA9VL759768	34841596	3031750	350	1800	1350	1200	12328.5	342946.7	43933.4	7.8	102.9	210.7	2	186.3	256.5	2	556
50	M11-350E+	1FUWDMDA8VL759776	34842031	3032335	350	1800	1350	1200	13188.7	308005.8	41213.6	7.5	409.5	1046	8	118.1	200.6	2	519
51	M11-350E+	1FUWDMDA7VL759770	34841446	3031479	350	1800	1350	1200	12387	346917	41524.1	8.4	38	90.8	1	81.5	113.6	1	808
52	M11-370E			707644	370	2000	1350	1200	14301.3	224541.6	43767.3	5.1	5728.4	7828.6	55	2.1	2.3	0	
53	M11-370E	1FUY3MCB0TH674839	34789874	722478	350	2000	1350	1200	13050	406011.7	61563.1	6.6	2071.1	3939.9	30	1074.4	1703.4	13	101
54	M11-370E	1FUY3MCB2TH674812	34789141	101011	350	2000	1350	1200	3769.1	126264.9	19509.4	6.5	151.5	334.1	9	9.5	15.4	0	823
55	M11-370E	1FUY3MCB5TH674822	34789151	148955	350	2000	1350	1200	13528.3	392629	63339.6	6.2	1562.3	3569.4	26	1673.5	2491.3	18	164
56	M11-400e+			2042869	350	1800	1350	1200	10884.1	289794.5	35644.4	8.1	2014	4598.7	42	137.5	181.6	2	226
57	M1-400E+	1FUW3MCA2WL967013	34902111	17597	400	2100	1350	1200	9925	304333.6	39229.5	7.8	55.1	125.5	1	334.8	419.2	4	520
58	M11-400E+	1FUW3MCA9WL967008	34902106	16446	400	2100	1350	1200	10455.3	319784.5	39862.9	8.0	11.8	32.5	0	115.1	197	2	439
59	M11-400E+	796809	34807648	3024348	350	1800	1350	1200	9415.3	285747.3	33501.4	8.5	1367.3	3057.7	32	312.1	510.8	5	229
60	M11-400E+	1FUW3MCA9VL757720	34833230	3017215	400	2100	1350	1200	8715.2	284123.7	37435.4	7.6	1195.5	2475.7	28	37.4	67.8	1	231
61	M11-400E+	730168	34810451		350	1800	1350	1200	12372	437587	60578.4	7.2	1536	2790	23	1321.3	594.6	5	150
62	M11-400E+		34859646	3079111	350	1800	1350	1200	9567	447383.1	57504.9	7.8	571.6	1096.2	11	15.1	22	0	146
63	M11-400E+	1FUY3MDB8WP954131	34885768	3097662	400	2100	1450	1200	14946.4	398954.7	59549.4	6.7	283	560.1	4	3625.1	6731.7	45	164
64	M11-400E+	1FUY3MDB5WP954152	34890930	405	400	2100	1450	1200	12825.6	316347.6	48542	6.5	256.8	474.1	4	4080	6386.7	50	208
65	M11-400E+	1FUY3MDBOWP954172	34891553	1522	400	2100	1450	1200	17517.9	403980.9	65157.8	6.2	29.9	295.6	2	6633.1	9778.9	56	162
66	M11-400E+	1FUY3MDB3WP906164	34868411	3070875	400	2100	1450	1200	16839.4	436027.6	66102	6.6	3159.1	6965.7	41	916	1651.3	10	150
67	M11-400E+	1FUY3MDB1WP906146	34865605	3065410	400	2100	1450	1200	21363.1	456065	73407.9	6.2	297.4	521.9	2	7911.5	12337	58	144
68	M11-400E+			2037780	400	2100	1450	1200	5884.2	230067.8	35415.5	6.5	463.1	1027.4	17	268.8	434.1	7	285
69	M11-400E+	1FVXDMCB1VP663345	34816840	3011758	400	1800	1450	1200	1676.6	64458.2	8274.3	7.8	8274.3	191.5	11	24.9	38.6	2	596
70	N14-350E	4V1JDBJF8RR830887	11719894	615730	350	1800	1350	1200	14837.5	745088.5	100780	7.4	7	13.6	0	1.8	2.7	0	67
71	N14-370E	1FUYBCYB2RP424880	11721928	617131	370	1800	1400	1200	15199.5	495527.9	78389.6	6.3	1014.6	1745.6	11	3126.5	4573.7	30	103
72	N14-370E+	4VG7BBJF8XN769048	11905556	26554	370	1800	1450	1200	12334	526956	77317.4	6.8	1578.6	2079.4	17	1.5	1.5	0	124
73	N14-370 ESP+	758415R	11844447	3057719	370	1800	1450	1200	13504.3	469304.2	65986.1	7.1	2542.3	3975.4	29	579	679.6	5	140
74	N14-370ESP+	1FUYDDYB3	11864867	3092109	370	1800	1450	1200	8670.5	317378.4	44467	7.1	892.4	2069.1	24	377.1	661.2	8	206
75	N14-370E+	1FUWDCYA8WL808920	11846543	3900447	370	1800	1450	1200	20551	1032566	156550.5	6.6	747.1	1146.6	6	38	51.4	0	136
76	N14-370E+	4VG7BBJFFOXN769660	11901698	20912	370	1800	1450	1200	13226.2	577694	88522.3	6.5	1694.5	2150.6	16	3.3	3.6	0	113
77	N14-370E+	4VG7BBJF8XN769678	11902647	11761	370	1800	1450	1200	12990.8	571588.7	86262.6	6.6	1657.6	2071.9	16	1.9	2	0	115
78	N14-370E+	4VG7BNBJF4XN769676	11902407	22673	370	1800	1450	1200	12691.5	552138.8	82483.5	6.7	1760	2042.8	16	0.8	0.7	0	119
79	N14-370E	1FUYDCYB0SP681410	11742339	666803	370	1800	1450	1200	8331.9	246548.7	36663.1	6.7	210	347.3	4	103.1	130.7	2	462
80	N14-370E+	4VG7BBJFXXN769052	11905561	26560	370	1800	1450	1200	12675.3	535911.3	81019.1	6.6	1783.5	2263.7	18	1.4	1.4	0	122
81	N14-370E	653787	11745727	107209	310	1800	1250	1200	17145.8	615223.9	95511.8	6.4	2370.8	3636.5	21	457.9	756.5	4	97
82	N14-370E+	4VG7BBJF8XN769051	11905562	25777	370	1800	1450	1200	12330.6	544508.6	80800	6.7	1506.5	1949.6	16	1.6	1.7	0	120
83	N14-370ESP+	1FUYDDYB5WP928335	11867697	3096952	370	1800	1450	1200	8570.1	349995.6	49846.3	7.0	458	1045.8	12	12.5	17.1	0	335
84*	N14-370E		11749107	136548	400	1800	1450	1200	71.1	694.6	104.4	6.7	22.5	42.2	59	6.4	9.1	13	1240
85	N14-370ESP+	1FUYDDYB4WP928343	11862902	3089011	370	1800	1450	1200	6673.3	282543	40788	6.9	560.4	1056.6	16	34.4	41.9	1	232
86	N14-370ESP+	1FUYDDYB6WP928344	11862893	3086798	370	1800	1450	1200	7593	331699.2	43597.8	7.6	595	1139.9	15	115.5	145.2	2	198

87	N14-370ESP+	1FUYDDYB6WP928389	11865978	3094510	370	1800	1450	1200	7704.2	296654.2	46385.8	6.4	128.8	295.7	4	111.5	156	2	384
88	N14-370ESP+	1FUYDDYB5WP928349	11866212	3094723	370	1800	1450	1200	7920.8	316101.4	46400.9	6.8	36.4	68.8	1	126.5	177.2	2	382
89	N14-370ESP+	1FUYDDYB3WP28379	11865461	3900499	370	1800	1450	1200	7337	254264	40278.5	6.3	797.3	1842.8	25	673.8	1005.6	14	258
90	N14-370ESP+	1FUYDDYB9WP928399	11862895	3086817	370	1800	1450	1200	8677.9	303664.5	47041.3	6.5	3.6	5.2	0	3.5	3.6	0	233
91	N14-370E+		11806335	2032053	370	1800	1450	1200	15376	587391	98013.6	6.0	379.5	663.1	4	2307.8	1193.2	8	275
92	N14-370ESP+	4VG7DEJH3XN758679	11894912	8053	370	1800	1450	1200	11748.6	341720.2	53267.4	6.4	399.4	743.1	6	1754.1	2671.1	23	291
93	N14-370E+	4329126	11840017	3049654	370	1800	1450	1200	11192.9	382481.7	69563.1	5.5	2167	2882	26	190.8	199.4	2	171
94	98 N14-410	4VG7BBJF6XN769677	11902412	21485	370	1800	1450	1200	13441.4	577792.8	88350.5	6.5	1888.3	2432.9	18	1	0.9	0	113
95	N14-410E	4329066	11838979	3900073	370	1800	1450	1200	11225	370150.6	69358.5	5.3	2140.5	2888.1	26	187.3	222	2	177
96	N14-410E		11799677	2043370	370	1800	1400	1200	14793.6	180095.1	28617.5	6.3	863.1	1438.8	10	45.9	51.7	0	144
97	N14-410E	1FUYDCYB6VH575347	11804214	2030321	370	1800	1450	1200	12223.5	432217.8	64825.5	6.7	2416.1	4390.3	36	276.3	364	3	152
98	N14-410E	1FUYDCYB6VH575347	11804214	2030321	370	1800	1450	1200	12223.5	432217.8	64825.5	6.7	2416.1	4390.3	36	276.3	364	3	152
99	N14-410E		11799677	2043370	370	1800	1400	1200	14793.6	180095.1	28617.5	6.3	863.1	1438.8	10	45.9	51.7	0	444
100	N14-430E	1XKDD69XXPJ587082	11661875	324946	430	2100	1450	1200	6654.2	214916.2	40062.3	5.4	417.3	1865.3	28		156.1	2	
101	N14-435E	4VG7DAJH4WN739937	11833779	3041418	370	1800	1450	1200	12815.4	476598.3	70115	6.8	8.8	13.3	0	10	13.9	0	486
102	N14-435E+	1FUYDDYBXWP940075	11884759	20673	435	1800	1450	1200	13513.1	302030.4	55102.3	5.5	7701.5	7502.8	56	215.6	262.8	2	217
103	N14-435ESP+	1FUWSDZA8VP796382	11825139	3027824	435	2100	1550	1200	7011.1	267052	41986.8	6.4	1447.5	1759.2	25	3.3	2.9	0	245
104*	N14-460E	419666	11690764	47441	1575	2100	1550	1200	66.1	952.9	131.1	7.3	7.9	43.9	66			0	
105	N14-460E+	4VG7DAJH0XN774184	11912336	30824	460	2100	1650	1200	17798.2	440326.9	76528.9	5.8	747.1	619	3	6864.6	9501	53	149
106	98 N14-475	766710J	11890070	4213	460	2100	1550	1200	15582.2	452320.3	69728.1	6.5	9.1	10.9	0	0.8	0.8	0	2937
107	98 N14-475	1FUYSDYB6XPB35961	11925991	58103	460	2100	1450	1200	7512.6	348907.6	52683.9	6.6	594.1	918.4	12	0	0	0	188
108	98 N14-475	782005J	11912500	29183	460	2100	1650	1200	14185.7	497502.6	71422.9	7.0	1688.6	2933.3	21	35.1	49	0	215

*: Outlier vehicles

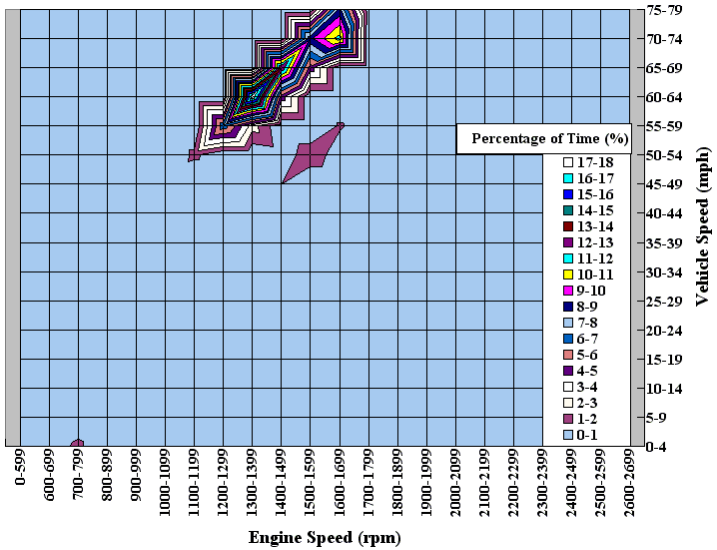
Appendix C. CAT Data

Vehicle #	Engine Model	VIN	Engine Serial Number	ECM Serial Number	Advertised Power	Governed Speed	Peak Torque	RPM at Peak Torque	Total Time	Total Distance	Total Fuel Used	Total Fuel Economy	Total Idle Fuel	Total Idle Time	Total PTO Fuel	Total PTO Time	Averag Load Factor	Rating type
1	3406E	0SO389341D	5EK48152	08850004CA	500	2100	1649	1200	26758.3	631425	160419	3.9	9971	13580.3	110	9.57	50	Standard Low NOx Kit
2	3406E	656628	5EK40442	01050385CA	434	1800	1650	1200	20897.4	844352	145424	5.8	3421	5890.7	20	1	27	Standard
3*	3406E	839025J	2WS17288	12990070KA	435	1800	1550	1200	2432	289672	50009	5.8	3223	6675.9	0	0	35	Standard
4	3406E	483523D	1LW25829	27080582CJ	434	1800	1550	1200	14224	450646	78085	5.8	3967	6692.5	1	0.35	56	Multi-Torque
5*	3406E	477356D	2WS10123	23315243KM	435	1800	1550	1200	5187	468328	85594	5.5	3998	6407.6	0	0	2503	Multi-Torque
6	3406E	421561D	5EK96659	29660273CJ	434	2100	1650	1200	29634.4	481462	109251	4.4	15313	20263.55	0	0.05	49	Standard
7	3406E	483524D	1LW26001	26880096CJ	451	2100	1550	1200	16703	447374	74506	6.0	6233	8332	0	0	50	Standard Low NOx Kit
8	3406E	477185N	1LW26221	26780015CJ	475	2100	1750	1200	12569	347614	65580	5.3	3238	6364.2	0	0.05	51	Standard
9	3406E	1FUYDXYB4VH833873	5EK84125	21260016CG	410	1800	1550	1200	15598.1	511455	79514	6.4	3528	6310.3	1	0.45	47	Standard
10	3406E	1FUPCXYBXXPA51166	2WS01496	34180105KA	475	2100	1750	1200	5299.1	309231	59264	5.2	6389	35.8	0	0	26	Standard
11*	3406E	1FUPCXZB5YL586207	2WS31556	24190184KA	500	2100	1600	2120	843.5	282886.8	53957.5	5.2	3614.2	4944.2	0	0	36	Standard
12*	C 12	458042D	2KS05441	05090024KA	380	1800	1450	1200	5463.5	128831	346491	0.4	1086.4	979.4	0	0	32	STANDARD
13	C 12	2744	9NS02214	31870161CJ	429	2100	1652	1200	2301.5	76299.6	12106.1	6.3	248.3	876.3	0	0	45	STANDARD
14	C 12	2FUYDWEB3WA830594	1YN09541	16070157CJ	410	2100	1550	1200	19012.5	515937.5	86206.3	6.0	7572.9	9680.5	0.3	0.1	47	STANDARD LOW NOX KIT
15	C 12	2FUYDWEB2WA830599	1YN09621	14970266CJ	410	2100	1550	1200	6219.1	151728.1	27520.4	5.5	3043.4	3437.1	0.1	0.3	47	STANDARD LOW NOX KIT
16	C 12	2743	9NS02150	31570011CJ	380	1800	1452	1200	445.7	16672.4	2732.1	6.1	47.5	140.9	0	0	45	MULTI-TORQUE LOW NOX KIT
17	C 12	176 476565	9NS07795	08080260CJ	380	1800	1452	1200	9420.9	257134.7	48871.4	5.3	2228.8	4942.8	0	0	55	MULTI-TORQUE
18	C 12	2FUYDWEB9WA830597	1YN09484	14270414CJ	410	1800	1550	1200	18159.6	423240	68483	6.2	7327	9233.9	7327	0.15	40	MULTI-TORQUE
19	C 10	1HSHBATN4VH437534	2PN02870	2906031500	335	1800	1350	1200	11528.5	333368.2	46985	7.1	3188.9	3512.1	0	0	40	STANDARD
20	C 10	2HSFMATR0WC049965	2PN06457	25570149CJ	370	1800	1350	1200	5163.2	148448	21370	6.9	1290	1412.4	0	0	35	MULTI-TORQUE
21	C 10	3815	8X50X735	0113006705	335	2100	1251	1200	1515.7	53170	8646.9	6.1	84.4	334.8	0	0	48	STANDARD
22	C 10	1FU5BECB6VL770440	2PN03137	31661177CJ	335	1800	1350	1200	12468.4	483640.4	71672.1	6.7	2298.5	2925.1	0	0	47	STANDARD
23	3176B	345100D	9CK08907	10340229CA	350	1800	1350	1200	1325.5	40565.4	7722	5.3	301.3	429.4	0	0	59	STANDARD
24	3176B	SO349351D	9CK03725	29930187CA	350	1800	1350	1200	20801.4	782025	101221	7.7	0.4	0.3	0	0	3	STANDARD
25	3176B	1HSHBATN1SH203667	9CK17774	35540041CA	325	1800	1250	1200	2925.7	81029.5	10690.8	7.6	152.5	617.7	0.1	0.1	37	STANDARD
26*	3176B	KENWORTH-939714-M	9CK22027	11550245CA	350	1800	1350	1200	5.4	168.2	18.1	9.3	1.3	2.1	0	0	31	STANDARD
27	3126B	1fv3gjac7yhg70284	3YL23436	27490094KC	190	2300	520	1440	674.3	15985.2	2168.9	7.4	29.3	49.7	0	0		STANDARD
28	3126B	1FV3GJAC3YHH10294	8YL40733	00200313KC	190	2300	520	1440	1078.4	25124.1	3380.6	7.4	22.8	42.3	0	0		STANDARD
29	3126B	1FV3GJAC3YHH10277	8YL41763	0100116KC	190	2300	520	1440	1181.3	27323.7	3814	7.2	20.4	33.1	0	0		STANDARD
30	3126B	1FV3GJAC6YHH10287	8YL41147	00900173KC	190	2300	520	1440	1294.3	30044.8	4164.3	7.2	38.3	67.8	0	0		STANDARD
31	3126B		8YL24126	30090199KC	190	2300	520	1440	1291.5	25894.5	3756.4	6.9	84.9	158.4	0	0		STANDARD
32	3126B	1FV3GJAC5YHH10314	8YL42037	31790105KC	190	2300	520	1440	1190.1	27624.2	3675.6	7.5	47.4	86.4	0	0		STANDARD
33	3126B	1FV3GJAC5YHH10264	8YL40363	00200344KC	190	2300	520	1440	1333.1	30409.9	4169.8	7.3	31.9	58.2	0	0		STANDARD
34	3126B	1FV3GJACXYHH10261	8YL40692	00200150KC	190	2300	520	1440	1438.1	32811.9	4509.8	7.3	26.5	47.5	0	0		STANDARD
35	3126B	1FV3GJAC9YHG31325	8YL17491	14100174KC	190	2300	520	1440	612.4	12647.8	1657.3	7.6	22.4	43	0	0		STANDARD
36*	3126B	1FV6HJBA6XHA26880	7AS33922	27480025FV	251	2200	660	1440	5109.5	4503	15871	0.3	1120	1677.2	0	0		STANDARD
37	3126B	1FV3GJAC6YHG70339	8YL23956	30190181KC	190	2300	520	1440	1385.9	28380.8	3825.5	7.4	31.8	50.6	0	0		STANDARD
38*	3406C	1FUYDXYBXRP452783	4CK21621	0PP5026064	425	2000	1450	1200			91158	0.0		106988				STANDARD

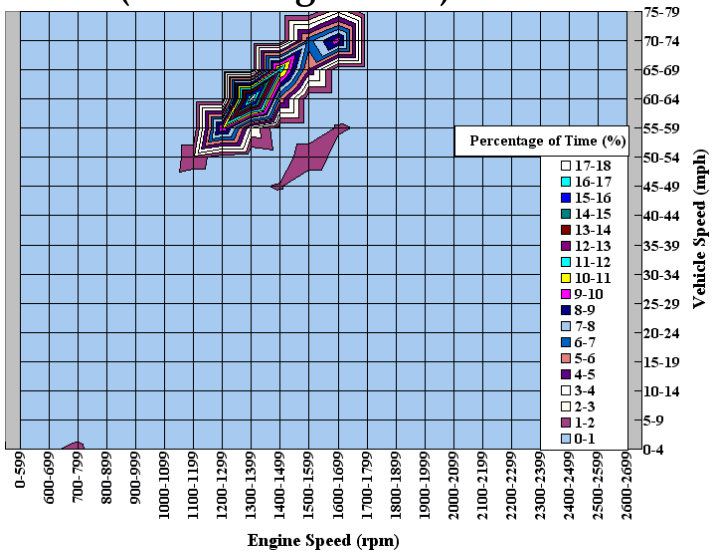
39*	3406E	9561	5EK19183	15740122CA	355	1800	1450	1200	31.4	1023.5	108.8	9.4	4.1	11.7	0	0	34	MULTI-TORQU
40*	3406E	2HSFHASR9TC077815	5EK60942	23450156CA	434	1800	1650	1200	52.4	2312.4	241.4	9.6	7.9	12.9	0	0	33	STANDARD
41*	3406E	1FUYDXYB2TH811819	5EK54883	15850279CA	434	9999	1650	2120	8.3	120.3	20.3	5.9	4.6	5.4	0	0	31	STANDARD
42*	3406E	1FUYDSYB8TP644441	SEK53292	14450233CA	355	1800	1350	1200	12.3	308.3	40.9	7.5	4.9	6.1	0	0	40	STANDARD
43	3406E	1FUYDXYB6TH81161C	5EK55130	10850216CA	434	9999	1650	1200	1215.1	37461.9	5895.1	6.4	367.9	567.3	0	0	45	STANDARD
44	3406E	5 651348	5EK24030	26340133CA	475	1800	1650	1200	688.7	19056.3	3227.8	5.9	189.1	265.2	0.1	1	37	STANDARD
45	3406E	1FUYDXYB1TH811827	5EK55409	16350251CA	434	9999	1650	1200	92.9	2889.3	620.5	4.7	25.8	44.1	0	0	63	STANDARD
46*	3406E	710524	5EK59829	22050084CA	355	1800	1450	1200	33.2	968.3	138.3	7.0	8.9	14.5	0	0	44	MULTI-TORQUE
47	3406E	1FUYDXYB8SP586648	5EK24717	206400360A	434	9999	1650	1200	127.8	4124.2	721.1	5.7	41.9	48.7	0	0	46	STANDARD
48	3406E	S0821066R	1LW31751	32180146CJ	475	2100	1750	1200	11205.4	487237	75189.5	6.5	1469.8	3341.2	0.1	0	49	STANDARD
49	3406E	460776D	1LW15951	22290030CG	475	2100	1649	1200	4383.6	132737.5	22739	5.8	1980.4	1984.9	0.1	0	41	MULTI-TORQUE
50	3406E	827996J	2WS04164	01295108KA	475	2100	1750	1200	3671	399253.1	68394.1	5.8	2583.9	5753.9	0	0	37	STANDARD
51	3406E	413479D	5EK71991	34650006CJ	550	2100	1850	1200	20472.5	765707.8	153038	5.0	7127	6836.9	0.6	0.3	49	STANDARD
52	3046E		5EK84500	14260078CJ	550	2100	1850	1200	16971.8	609874.4	113284	5.4	6353.5	6515.7	1.3	0.6	45	STANDARD
53	3406E	1FUYSXYB1XL944323	1LW12130	09580108CJ	475	2100	1750	1200	19184.5	582603.3	104378	5.6	49	9319.4	0.3	0.1	48	STANDARD
54	3406E	710533	5EK68456	30650028CJ	355	1800	1450	1200	24260.5	733363.9	121691	6.0	5116.6	10197	0.1	0.1	52	MULTI-TORQUE
55	3406E	1FUPCXZB1YP940466	1MM01045	20890245KA	600	2100	2050	1200	5338.4	204067.7	36871.4	5.5	1299.9	1664.4	0	0	32	STANDARD
56	3406E	1FUPCXZB3YP940467	1MM01036	20690190KA	600	2100	2050	1200	2611.2	321259.4	61796.5	5.2	6122.9	5570.2	0	0	24	STANDARD
57	3406E	9116	2WS07973	14490081KA	475	2100	1650	1200	274.2	50802.4	8503.1	6.0	368.1	486.9	0	0	38	STANDARD
58	3406E	1FUYSXYB0YPA74576	2WS41688	31590389KA	475	2100	1750	1200	5110.6	230221	34607	6.7	602.5	771.6	0	0	38	STANDARD
59	3406E	500707N	2WS08762	22105040KM	475	2100	1650	1200	648.9	64127.7	11641.5	5.5	754	870.4	0	0	39	STANDARD
60	3406E	S076888CR	67S26819	32470176CJ	475	1800	1650	1200	13514.9	606497.4	98139	6.2	2316.6	2482.8	1.6	1.3	46	STANDARD
61	3406E	1189	1LW23021	24080252CJ	455	1800	1649	1200	7116.3	195977.2	33859.3	5.8	2354.1	3752	0	0	48	STANDARD
62	3406E	Unit 1200	1LW23676	25580110CJ	455	1800	1649	1200	3305.3	103153.7	17954.1	5.7	981.4	1574	0.1	0.1	50	STANDARD
63	3406E	1FUYDXYB5XPA73061	1LW24429	20680138CJ	434	2100	1550	1200	3220.9	88014.5	13723.1	6.4	574.3	1127.5	0.3	0.1	35	STANDARD
64	3406E	740348	6TS02498	31770025CG4	475	1800	1650	1200	12978.4	441624.5	68153	6.5	4282.6	4776.8	0	0	42	STANDARD
65	3406E	1FUYDXJBOTM811818	2WS37652	28490005KA	475	2100	1750	1200	5747.1	172713	35259.3	4.9	2470.1	2854.3	0	0	36	STANDARD
66	3406E	1FUYSXYB6WL948639	1LW00544	33970167CJ	475	2100	1750	1200	13685.3	483776.9	76447.1	6.3	3561.1	5853.2	0.1	0	45	STANDARD
67	3406E	S0752910J	6TSO4331	05670052CJ	550	2100	1850	1200	549.5	10754.7	2445.1	4.4	367.3	349.7	0.1	0.1	48	STANDARD
68	3406E	1FUWDSYA4VL846945	5EK86025	16960121CJ	375	1800	1450	1200	20446.8	926059.2	146925	6.3	2699.6	4386.1	0.3	0.1	53	STANDARD
69*	3406E	S0378453D	5EK40331	01650202CA	434	1800	1650	1200	2.9	10.3	3.1	3.3	1.6	2.3	0	0	21	STANDARD
70	3406E	S07579870	6TS12683	15370105CJ	475	2100	1750	1200	18234.4	595720.4	105437	5.6	8527.6	8026.3	1	0.4	47	STANDARD
71	3406E	1FUPCXZB6YLB86216	2WS30107	23490073KA	500	2100	1650	1200	909.8	300608	54794.3	5.5	528	4806.9	0	0	34	STANDARD
72	3406E	1FUPCXZB7YLB86211	2NS27223	20990171KA	500	2100	1650	1200	1084.5	283611.8	54253.8	5.2	3762.4	5257.3	0	0	34	STANDARD

*: Outlier vehicles

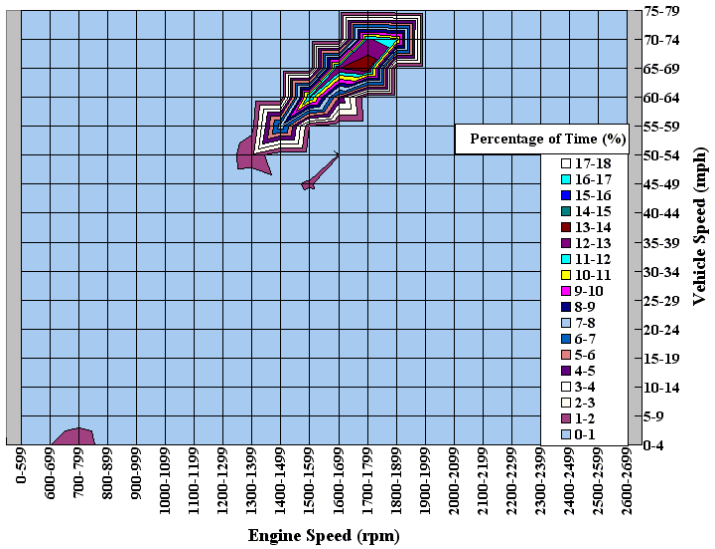
Appendix D-1. CAT Activity Plots (3406E Single Peak)



CAT Vehicle #4



CAT Vehicle #5



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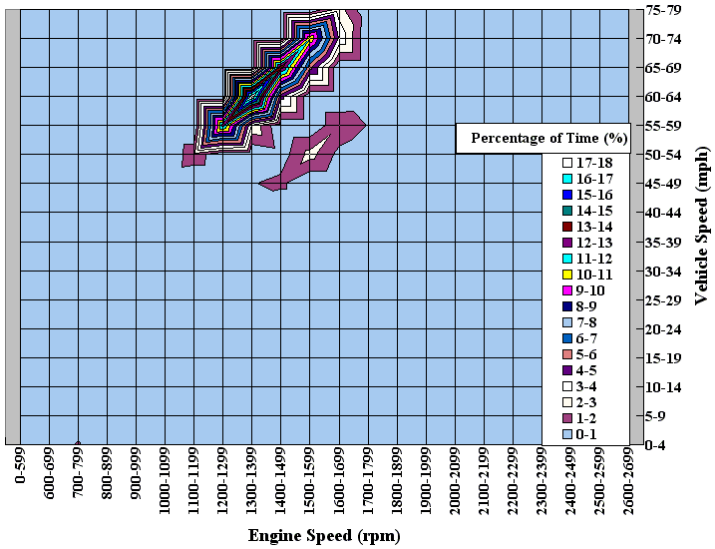

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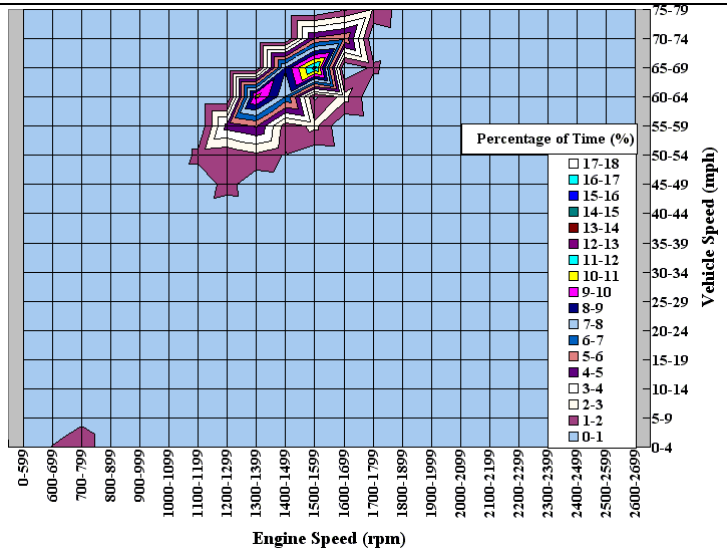

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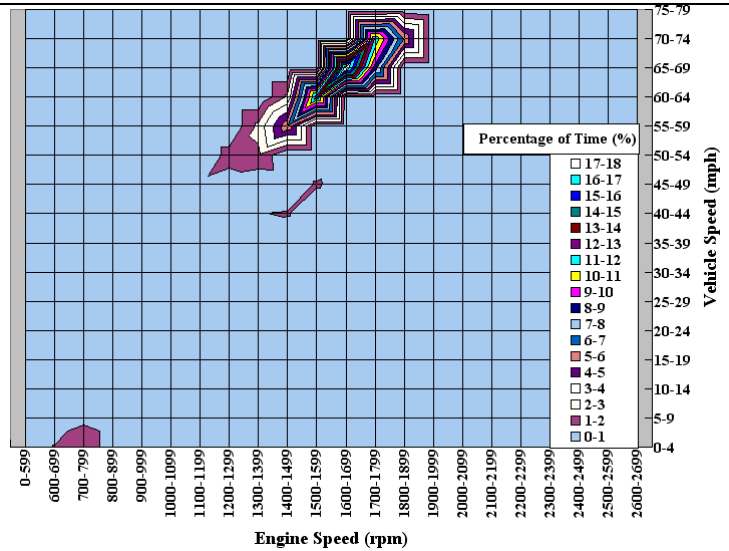

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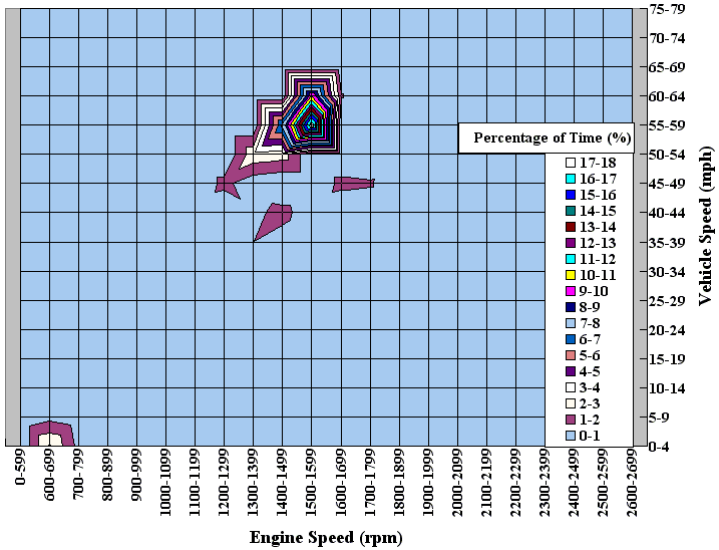

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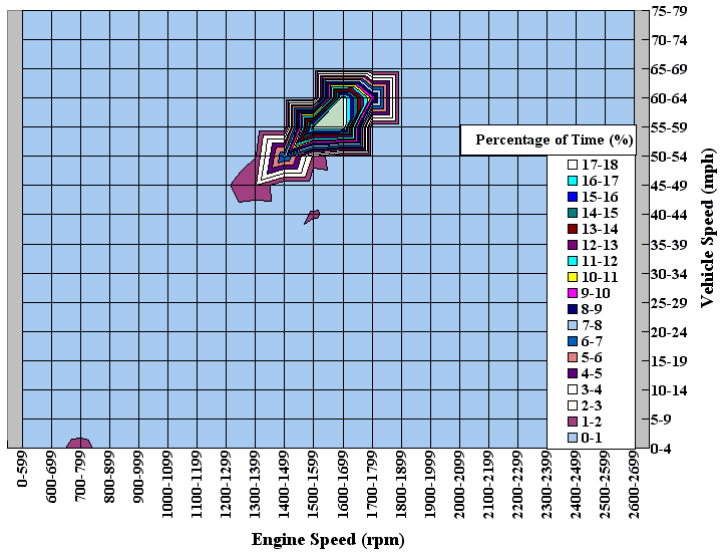

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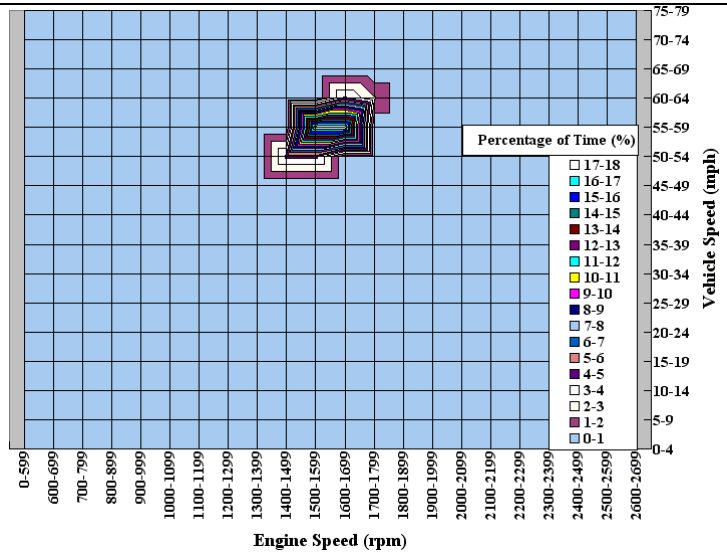

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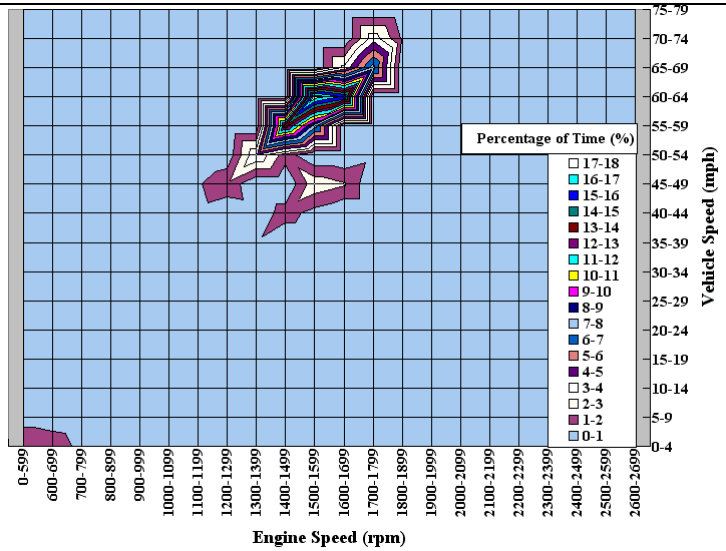

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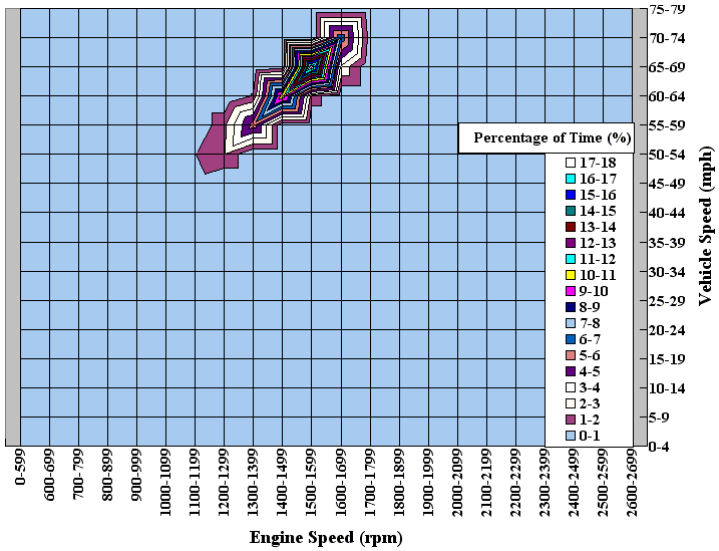

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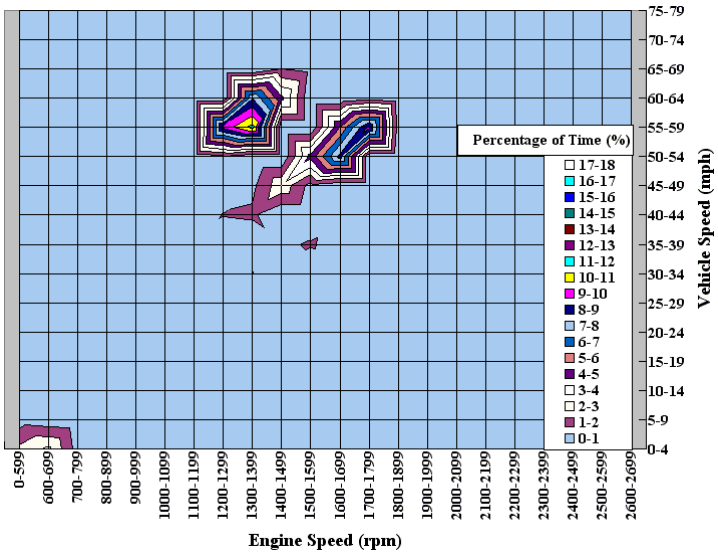

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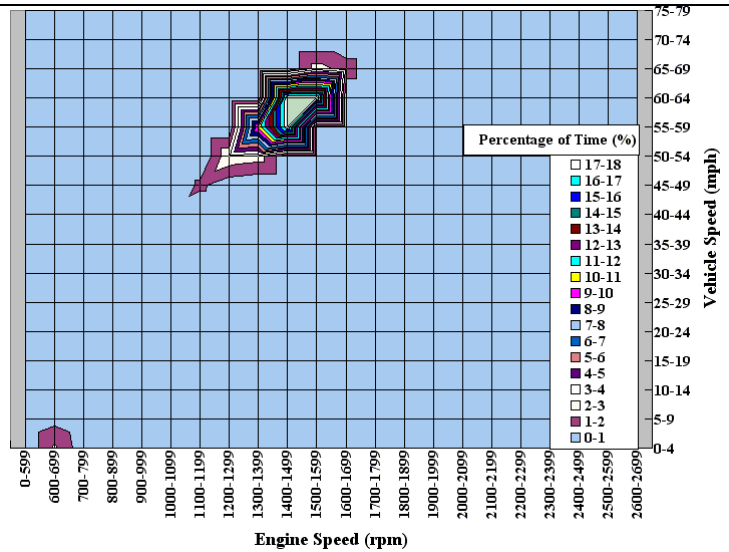

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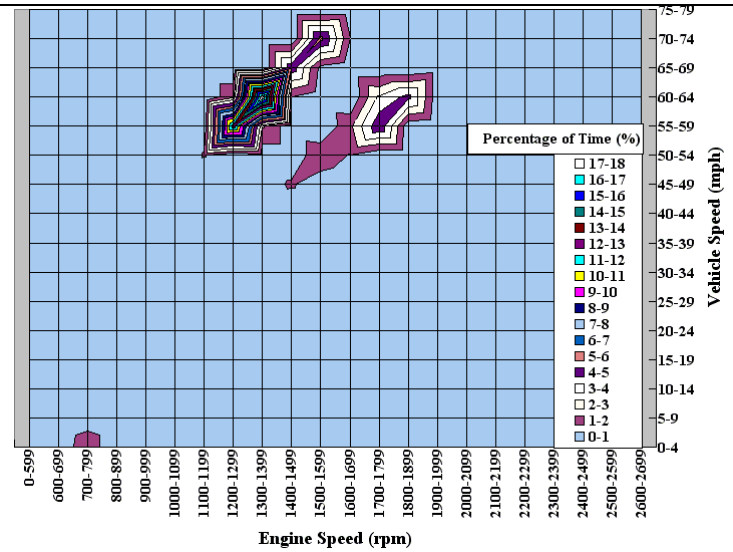
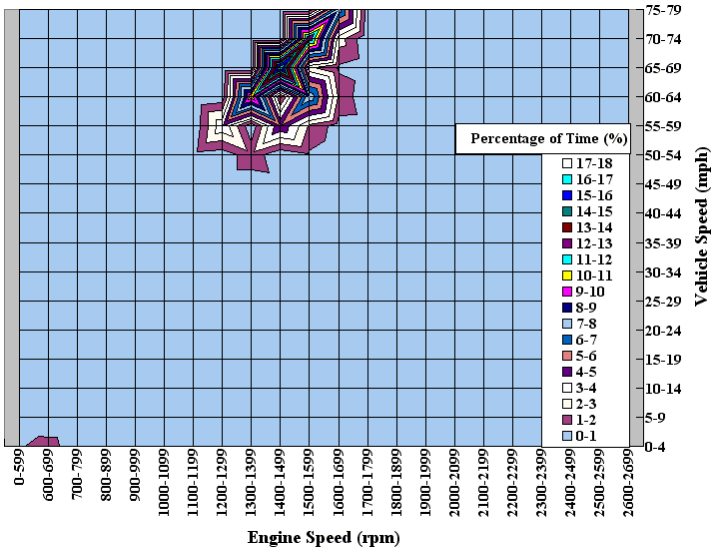


CAT Vehicle #47



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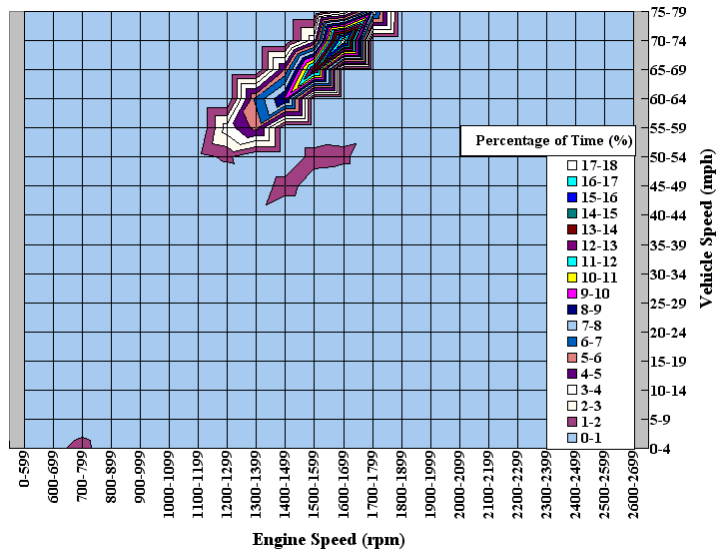
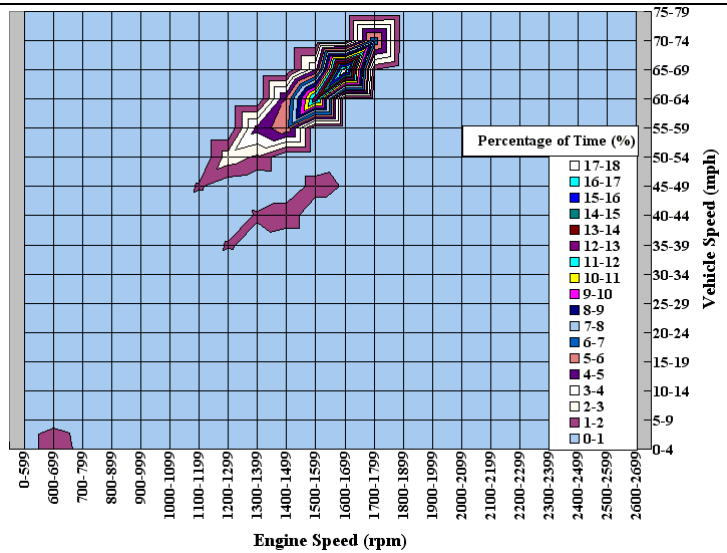


CAT Vehicle #53



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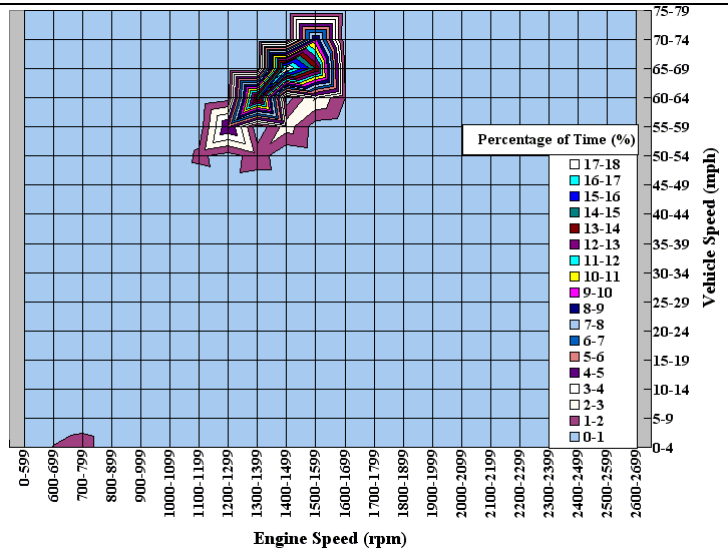

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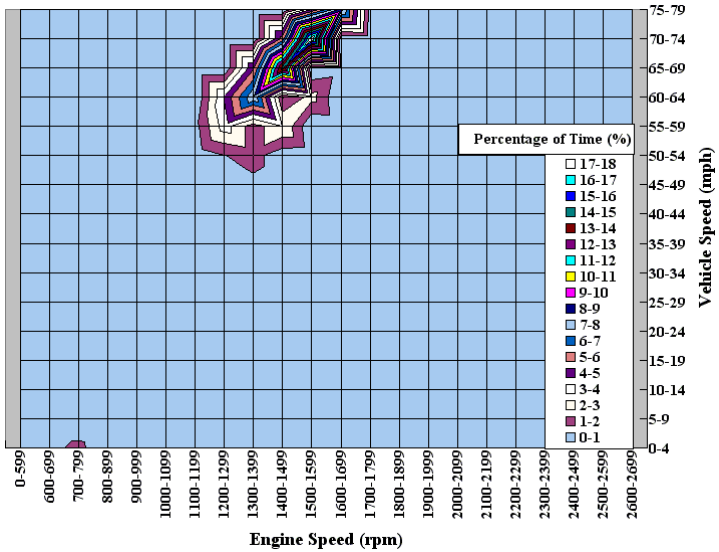

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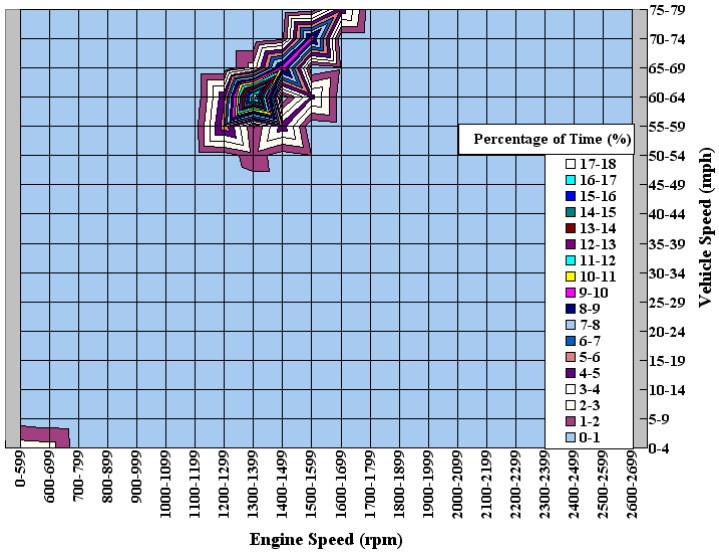
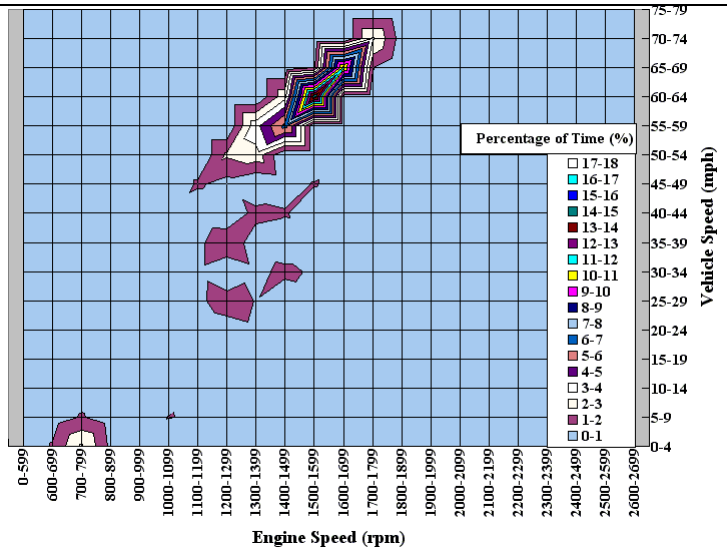


CAT Vehicle #60



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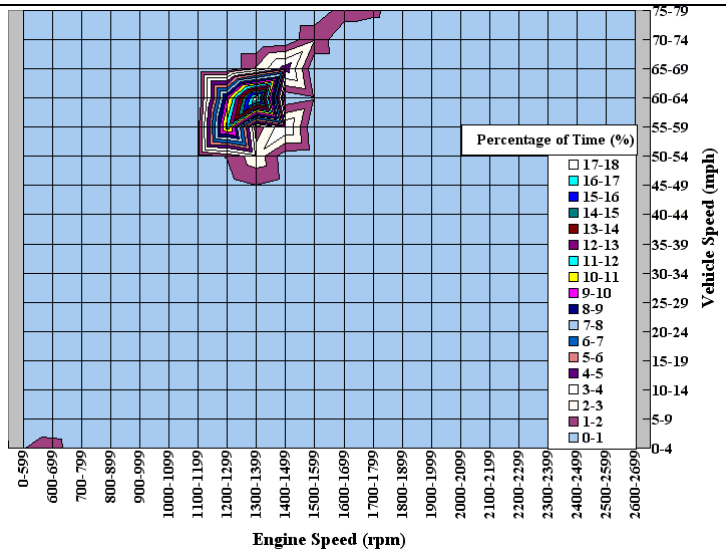

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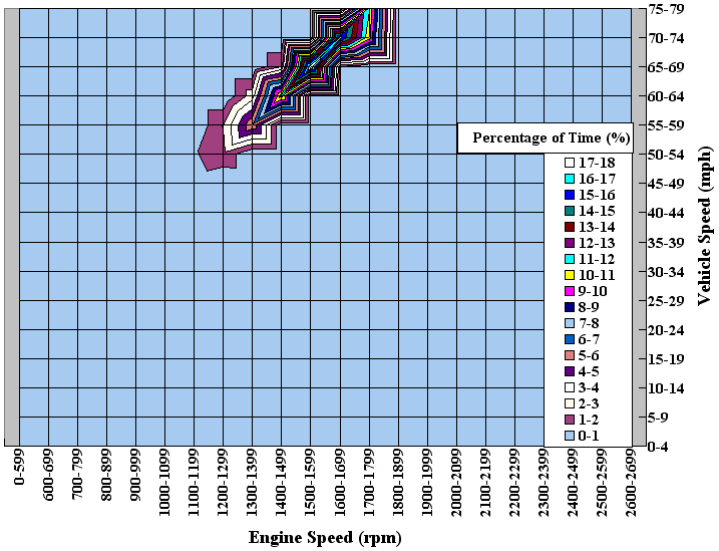

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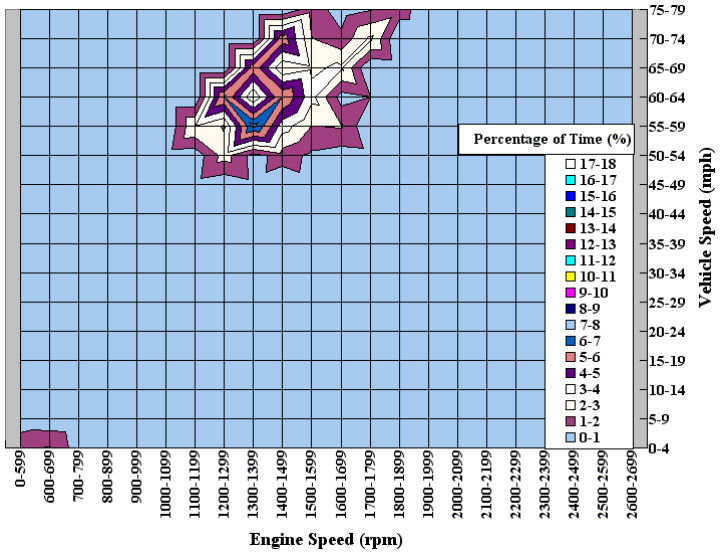

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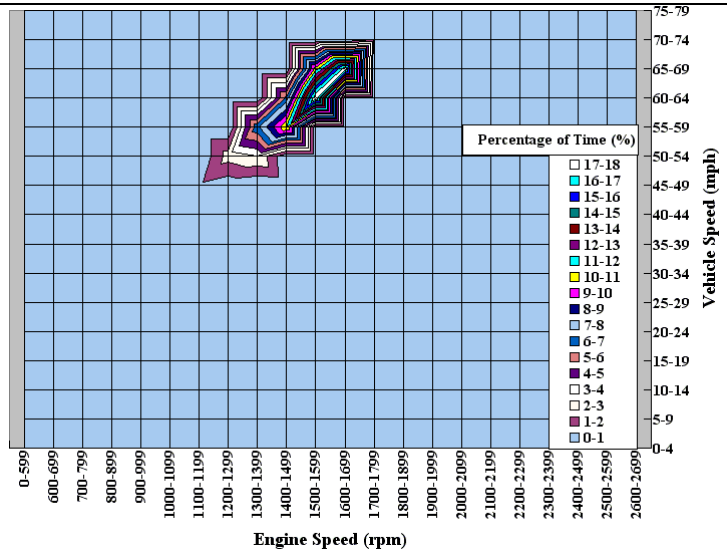
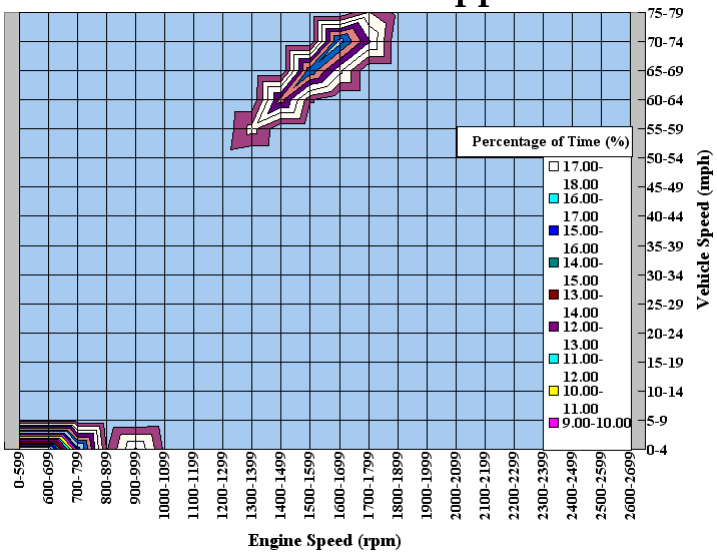
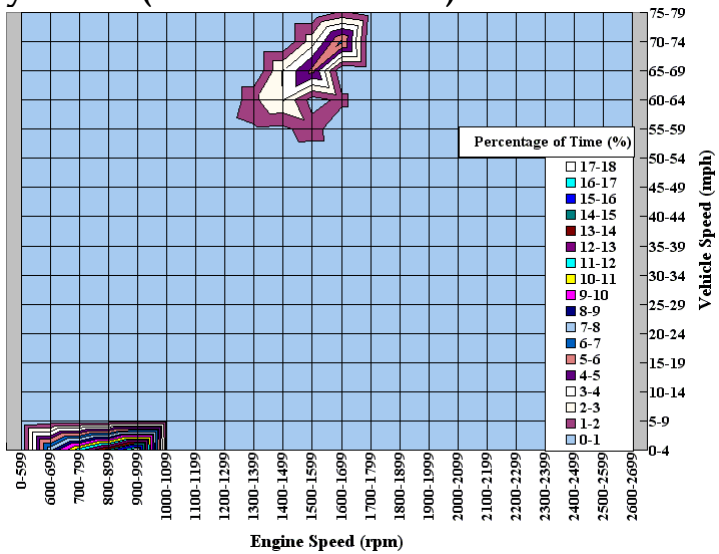


CAT Vehicle #68

Appendix D-2. CAT Activity Plots (3406E Two Peaks)



CAT Vehicle #3



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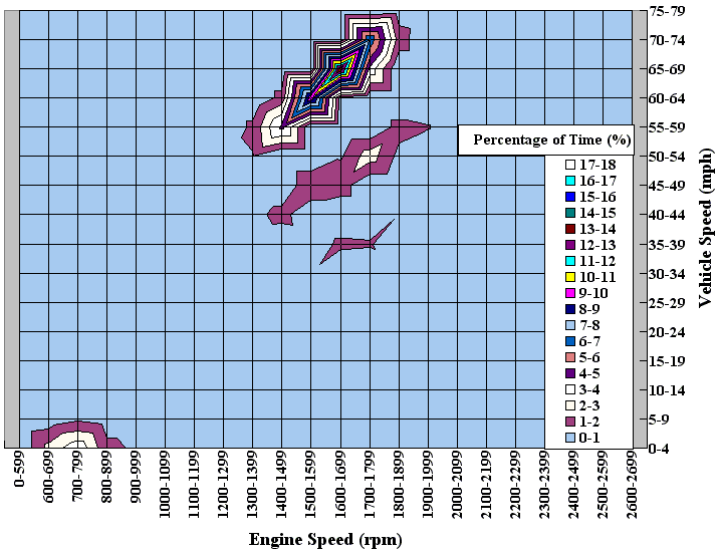

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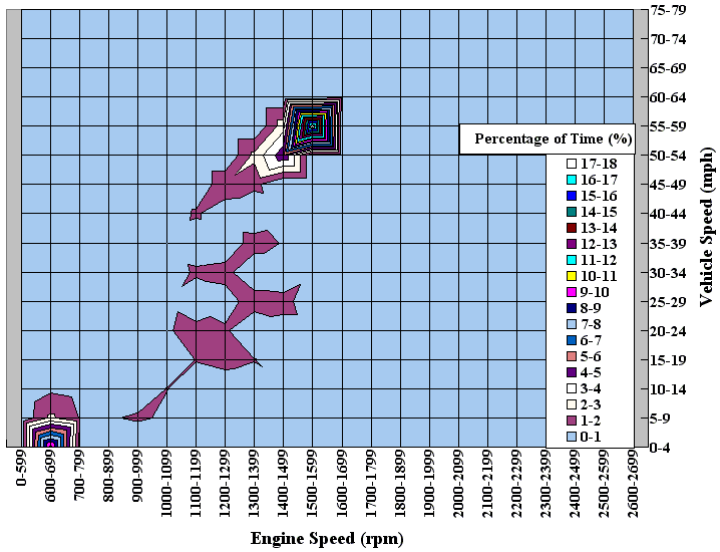

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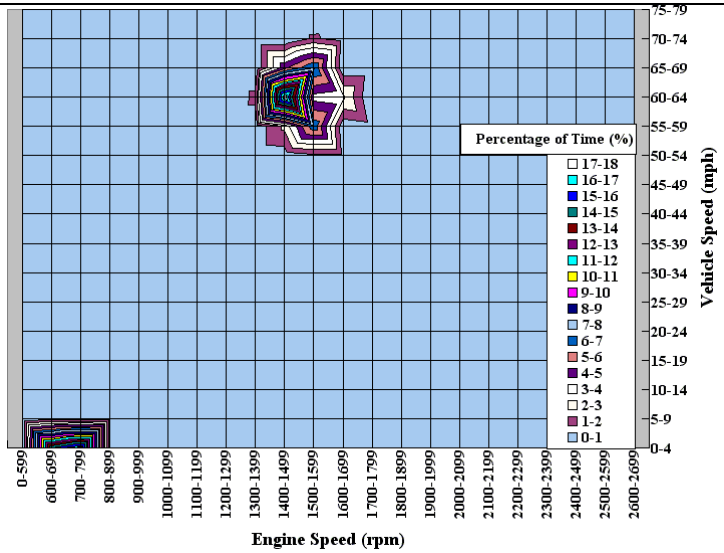

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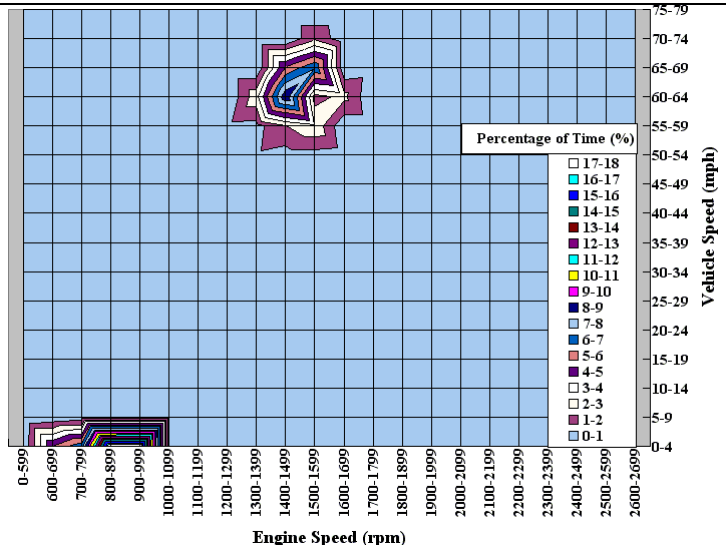

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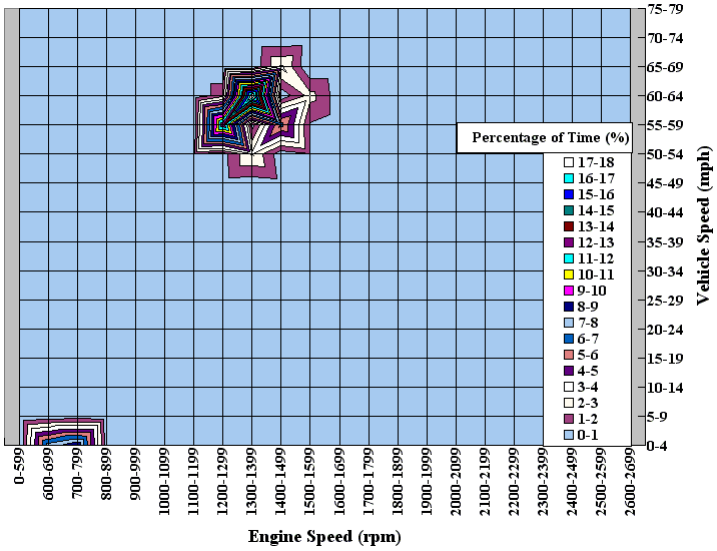

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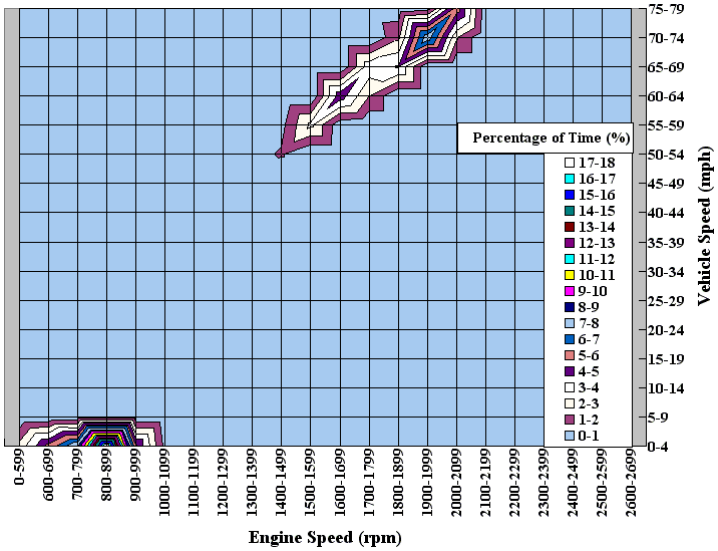

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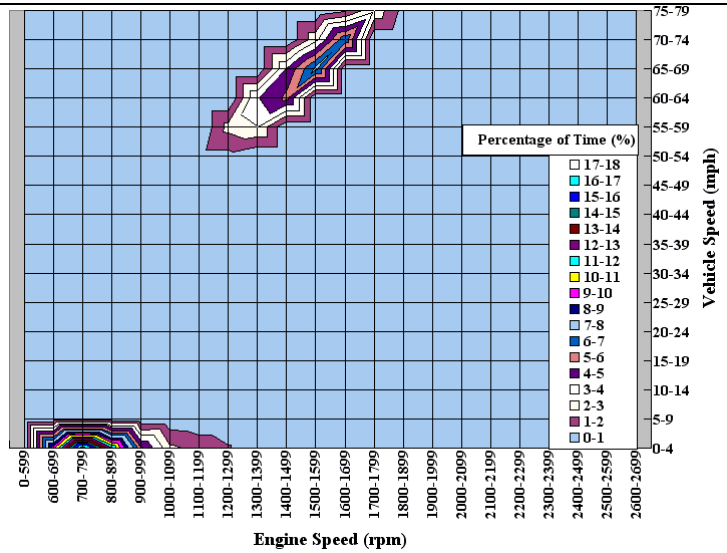

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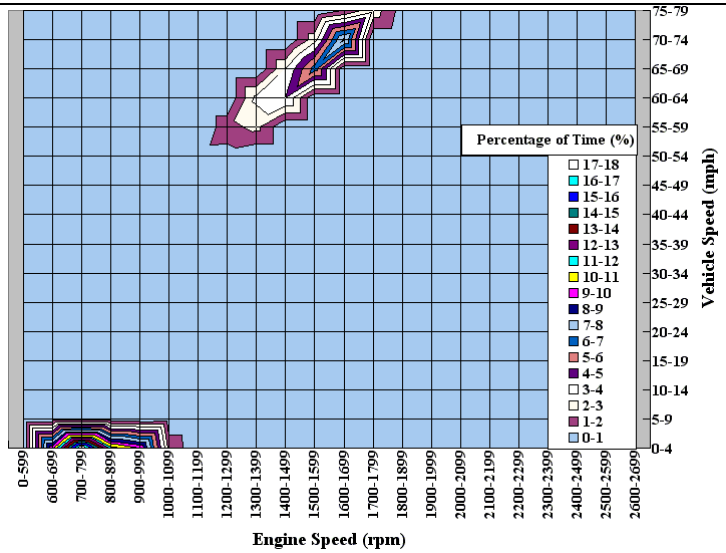
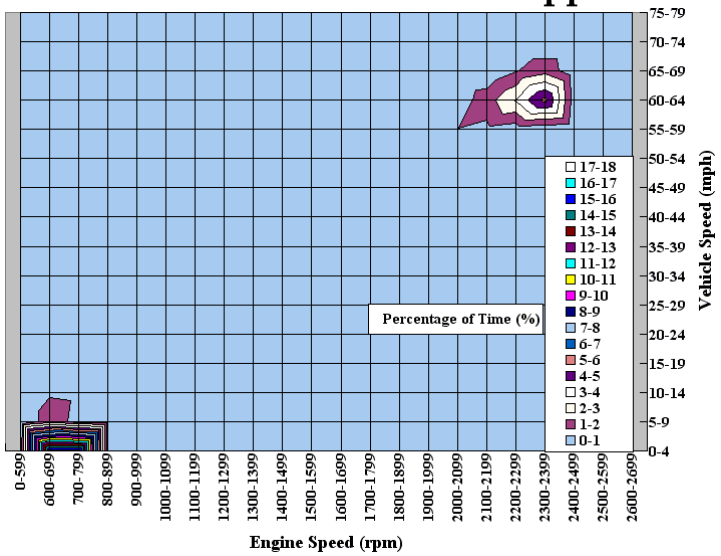
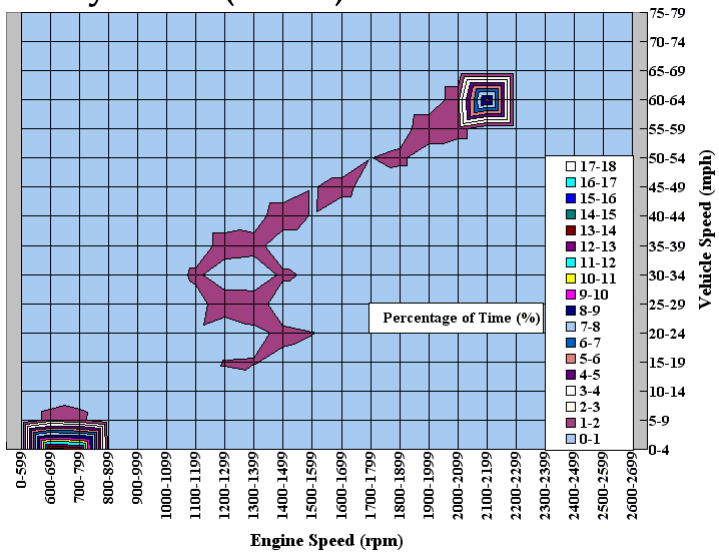


CAT Vehicle #72

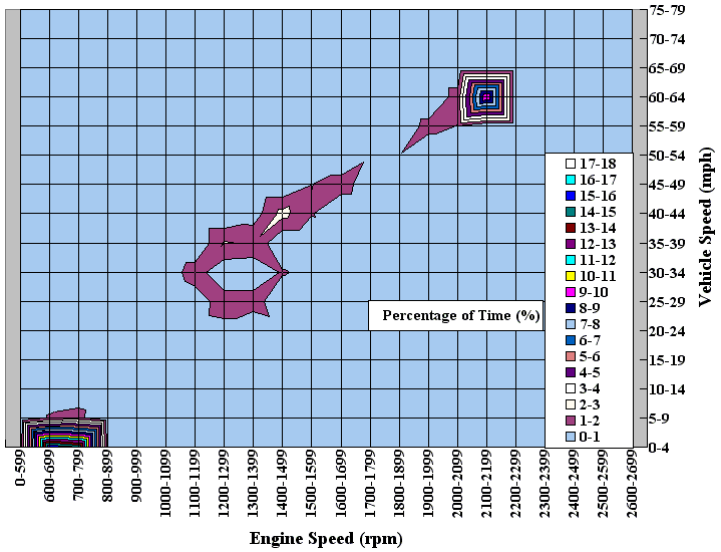
Appendix D-3. CAT Activity Plots (3126B)

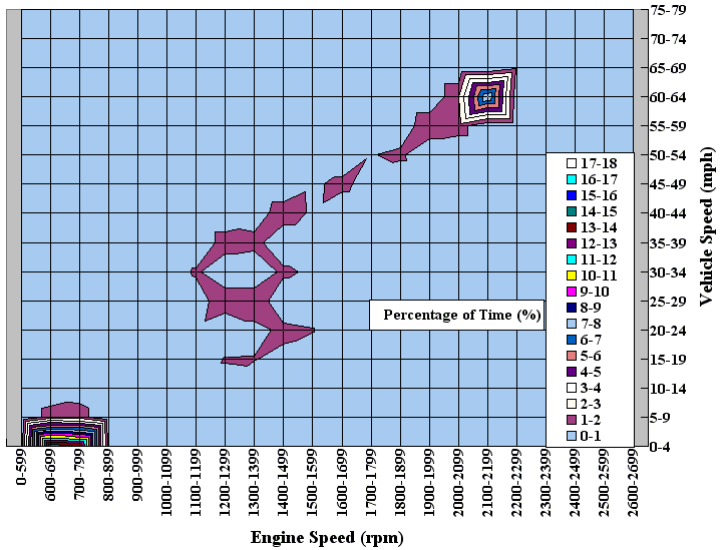


CAT Vehicle #27

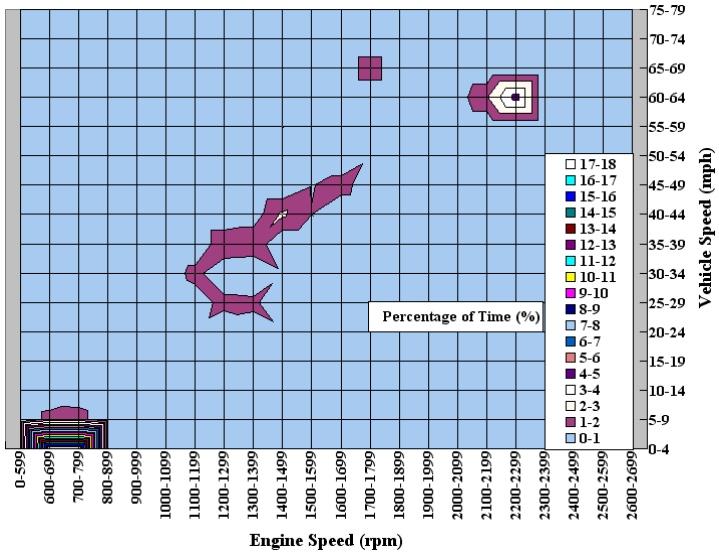


CAT Vehicle #28





CAT Vehicle #29



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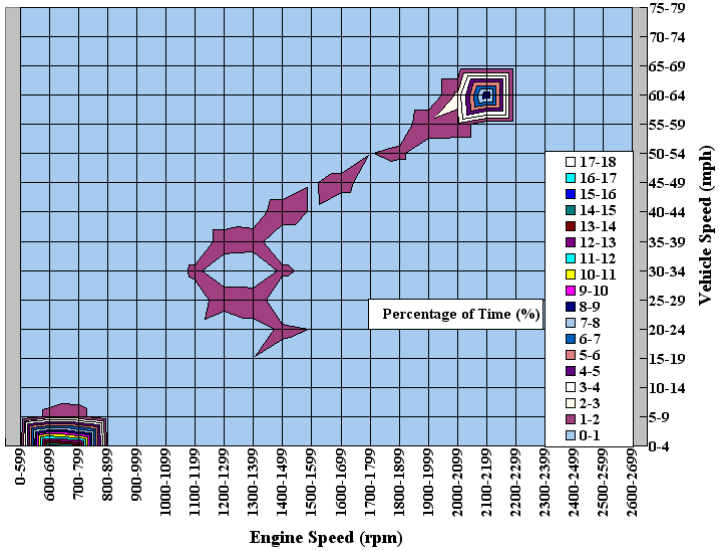
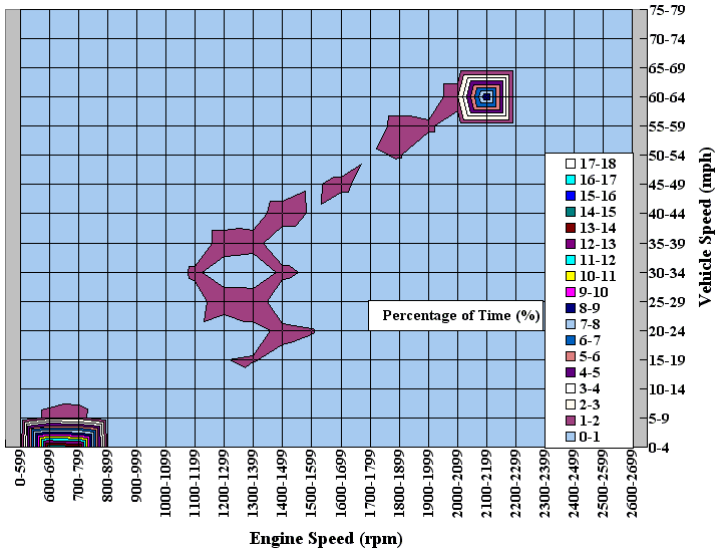


CAT Vehicle #31



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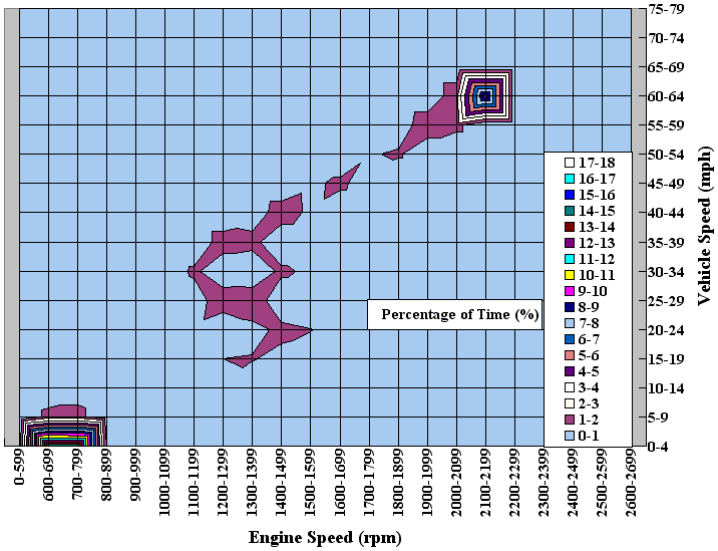
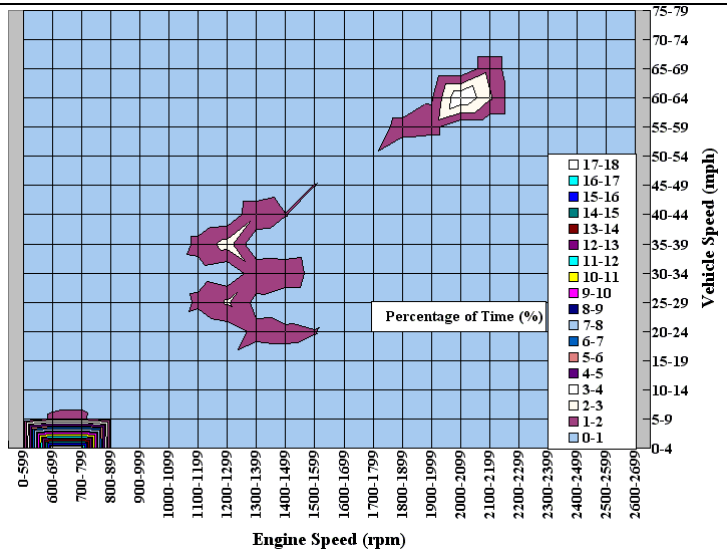


CAT Vehicle #33

CAT Vehicle #34



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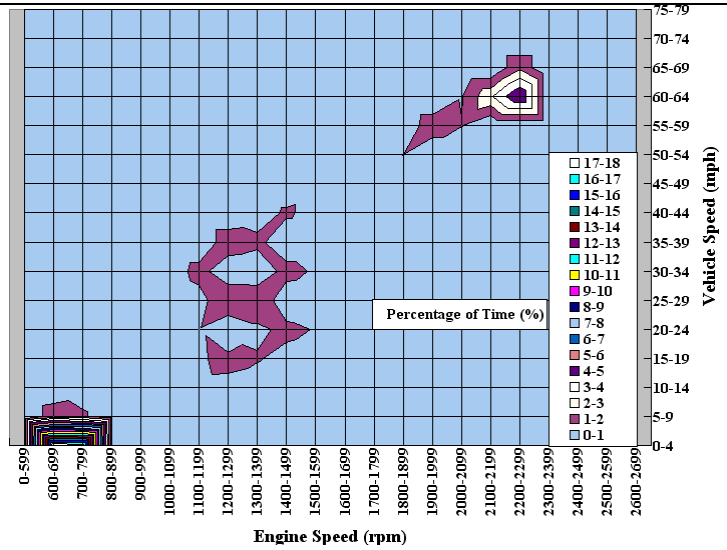


CAT Vehicle #37

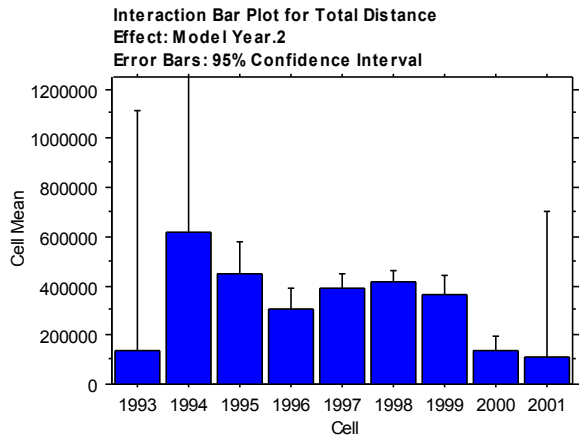
Appendix E VMT Analysis

Distance Traveled was averaged by Model Year (Table E-1, Figure E-1), and followed an increasing pattern as one would expect with the exception of the 2003 Model Year.

Table E-1. Average Total Distance by Model Year

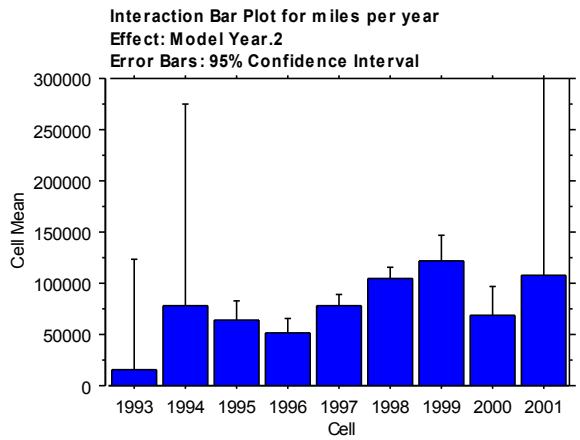
	Count	Mean	Std. Dev.	Std. Err.
1993	2	138194.9	108500.4	76721.3
1994	2	620308.2	176466.0	124780.3
1995	16	447950.8	241939.9	60485.0
1996	23	307480.6	198250.3	41338.0
1997	34	387996.9	166515.6	28557.2
1998	41	416213.8	147618.6	23054.2
1999	29	367795.9	190526.7	35379.9
2000	25	137060.2	138159.0	27631.8
2001	2	108524.3	66539.9	47050.8

The 95% confidence limits on total distance are large in 1993 and 2001 because of the variability and the small number of vehicles in the data set for those years.



Miles driven per year of operation show a declining trend over time, also as expected, though like Total Distance, there is considerable sampling variability (Table E-2, Figure E-2).

Table E-2. Average Total Distance Per Year of Operation

Means Table for miles per year
Effect: Model Year.2

	Count	Mean	Std. Dev.	Std. Err.
1993	2	15354.984	12055.596	8524.593
1994	2	77538.525	22058.249	15597.537
1995	16	63992.970	34562.845	8640.711
1996	23	51246.762	33041.718	6889.675
1997	34	77599.386	33303.127	5711.439
1998	41	104053.462	36904.655	5763.539
1999	29	122598.619	63508.911	11793.309
2000	25	68530.079	69079.509	13815.902
2001	2	108524.310	66539.865	47050.790