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Characterization of Drayage Truck Duty Cycles at the Port of Long Beach and Port of Los Angeles

Report

FINAL

(Revised)

Prepared for:
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TIAX Case D0529

1.0 Introduction

Approximately 11,000 heavy-duty diesel trucks currently perform drayage work at the Port of Long Beach and Port of Los Angeles, moving the majority of cargo that passes through the ports. Based on a 2009 emissions inventory of the ports, the drayage truck fleet is the second largest source of diesel particulate matter (DPM) and largest source of NOx emissions at the combined port complex. Increasingly tighter federal emissions regulations, accelerated fleet turnover via the Clean Trucks Program[1], and new state rules continue to reduce the contribution of diesel drayage trucks to the overall emissions inventory at the ports. The introduction of hybrid-electric or other advanced drive train technologies into the drayage fleet has the potential to further reduce emissions, while also decreasing petroleum consumption and lowering operating and maintenance (O&M) costs for fleet owners.

To successfully develop advanced vehicles for port drayage, equipment manufacturers must understand the typical duty cycles associated with drayage service. Superficially, drayage operations can be grouped into three categories based on the distance of the first move of the cargo: near-dock, local, and regional operation. However, optimized vehicle system designs will require significantly more detailed information regarding vehicle speed, engine power, and operating time in drayage service. The goal of this project is to collect detailed duty cycle information for drayage truck operations in near-dock, local, and regional operation. This duty cycle information can then be provided to equipment manufacturers to help accelerate and improve the development of advanced drayage trucks.

2.0 Project Overview

Nearly 40% of all containerized goods entering the U.S. move through the Port of Long Beach and/or Port of Los Angeles. The majority of these containers move by drayage truck to a variety of businesses, terminals, warehouses, trans-loading facilities, and container yards in Southern California. Once at these facilities, these goods may then be sent out for delivery to local businesses, loaded onto rail cars, repacked into dry vans, etc. While these facilities are spread out around Southern California, drayage operations are often grouped into three categories based on the first-move distance[2].

Near-dock Operation: This type of operation involves very short cargo moves from two to six miles in length, generally originating at the marine terminal. Cargo moves to the Intermodal Container Transfer Facility (ICTF), which functions as the Union Pacific rail terminal, or nearby container yards are included within this category.

Local Operation: A high concentration of warehouses and truck terminals, as well as a major rail yard (Hobart), exist within 20 miles of the ports. These terminals include distribution centers in downtown Los Angeles, Compton, and Rancho Dominguez. For the purposes of the current project, local operation is defined as cargo moves originating or terminating at the ports and having the other end point of the move between six and twenty miles distant from the ports.

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[1] http://portoflosangeles.org/ctp/idx_ctp.asp
http://www.polb.com/cleantrucks

[2] First-move distance represents the distance the cargo is moved from the port terminal to another facility or terminal before the cargo is loaded or unloaded from the truck.

Regional Operation: At distances greater than twenty miles from the ports, large warehouse facilities are common and may be used to transfer goods for interstate delivery. Under the current project, regional operation is described as cargo moves between 20 and 120 miles in length. This effectively covers drayage operations to the Mexico border to the south, Coachella Valley to the east, and Bakersfield to the north.

This project characterizes the duty cycle of drayage trucks operating in each of the three regions mentioned above. The typical duty cycle in these three regions differ significantly, primarily due to differences in relative amount of steady state and transient operation (e.g., highway cruise vs. stop-and-go).

3.0 Test Plan and Data Collection

Test Plan Overview

Driver behavior, in addition to day-to-day variations in route, workload and traffic can significantly affect the operation of a drayage truck. To account for these variations, the project test plan required the collection of vehicle operational data for multiple trucks over a period of several weeks. Specifically, a minimum of three trucks were required to be data logged and produce one week of data in each operating region, per truck. Based on conversations with the participating licensed motor carrier (LMC), K&R Transportation, it was assumed that each monitored truck could be dedicated to a particular operating region for a period of one week. At the end of the one week period, the truck would be reassigned to a new operating region for another one week test, until the three trucks had each gathered one week of data in each region of operation. However, rapid changes in the workload of the motor carrier due to seasonal increases in cargo flows required the LMC to alter the deployment of its drayage fleet. Specifically, the LMC began employing each truck in all operating regions (near-dock, local, and regional). Based on these changes, TIAX adopted the following approach to verify data was collected in all operating regions.

Data loggers were installed in three drayage trucks identified by the participating LMC. During the monitoring period, the LMC was expected to ensure that the trucks performed cargo moves within each of the three operating regions. TIAX periodically retrieved and reviewed data from the trucks to verify that data were being collected for each truck in each operating region. While each truck changed the region in which it operated from day-to-day, or operated in several regions during the same day, all three trucks did perform near-dock, local, and regional operations. As data was being collected in each region, it was determined to be sufficient to collect data from these three trucks over a period of at least three weeks. In total, ten weeks of data were collected; two trucks recording three weeks of data each while a third truck recorded four weeks of data.

Operating Parameters

Duty cycle information is typically represented by plotting vehicle speed versus time on a second-by-second basis. However, several other parameters are used to construct “typical” duty cycles from the numerous trips recorded during the data collection effort. In addition, it is anticipated that information related to engine load, fuel use, and engine revolutions per minute

(RPM) may be of significant benefit to a vehicle manufacturer during the design and optimization phases of product development. Therefore, the parameters given in Table 1 were collected to provide a more robust data set. In addition to the parameters recorded in Table 1, the vehicle specific information shown in Table 2 was also recorded.

Table 1. Logged Parameters

Parameter	Units
Speed	MPH
Distance	miles
Position	latitude/longitude
Idle Time	seconds
Operating Time	seconds
Acceleration	MPH/second
Engine Load	horsepower
Idle Fuel Use	gallons per hour
Fuel Use	gallons per hour
Throttle Position	%
Engine Speed	RPM

Table 2. Vehicle-specific Data

Parameter	Units
GVWR	lbs
Engine Power	HP
Truck Make	None
Truck Model	None
VIN	None
Engine Make	None
Engine Model	None
Transmission Type	Auto/Manual
Number of Gears	None

Data Collection Equipment and Operation

Under a previous demonstration program, the Port of Long Beach purchased a J1939[3]-capable AVIT[4] data logger with analog inputs and the associated DAWN software package from HEM Data[5]. This logger has the ability to collect data directly from a drayage truck's engine control unit (ECU). In addition, the logger can collect GPS data and analog signals; providing a complete data logging package. Based on the need to collect data from multiple trucks, the Port of Los Angeles purchased two additional, identical AVIT data loggers for this project.

Because the data collection system was installed on trucks performing actual drayage work for a period of several weeks, a series of custom cables and interfaces were created to allow the equipment to be placed out of the way of the drivers. Figure 1 depicts the location of the key components of the data collection system identified in Table 3 below.

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[3] J1939 is part of a set of standards defining communication of vehicle data over the on-board data bus.

[4] http://www.drewtech.com/products/avit.html

[5] http://hemdata.com/products/dawn

Table 3. Key components of the data collection system

Equipment	Manufacturer	Model	Purpose
Data logger	HEM Data	AVIT	Records data from the vehicle controller and other sensors (GPS, accelerometer, ignition
GPS receiver	Garmin	16X HVS	Reports the location, speed and direction of the truck
Ignition Sense Interface	Custom assembly using modified ATC fuse	None	Monitors the state of the ignition switch for use in determining key-on/key-off events
J1939 Interface	HEM Data	None	Interfaces data logger to the vehicle controller
Accelerometer	Custom assembly using Analog Devices sensor	ADXL335	Monitors vehicle incline and accelerations

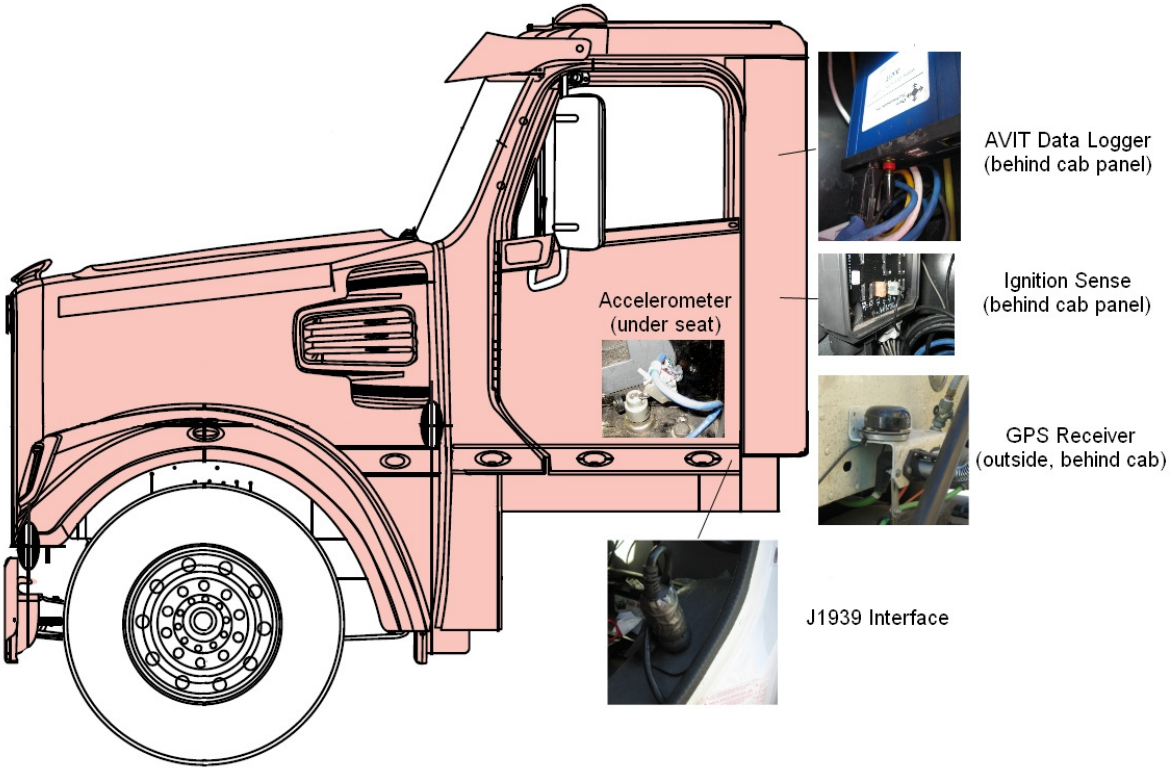

Figure 1. Location of key components of the data collection system (Image of cab courtesy of Freightliner)

The data collection system described above simultaneously collected data from the truck ECU, GPS receiver, and accelerometer. Data were recorded at 1 Hz (one sample per second), while the truck ignition was in the “run” or “on” position. When the truck was turned off, the logger saved the current data file and entered a low-power sleep mode. This resulted in the recording of a new file for each key-on event. Data were saved to a CompactFlash memory card internal to each logger. Files saved to the internal memory card were then transferred to a computer for further analysis using an Ethernet connection. This allowed TIAX to periodically collect data stored on the loggers without removing any equipment from the truck.

4.0 Data Analysis

Approaches to development of duty cycles have varied over the years, depending on the intended use and other factors like equipment type and available data. Under this test effort, TIAX selected a modal analysis approach similar to that used to create the Heavy-Duty Diesel Truck Test Schedule[6], albeit without the use of "microtrips". The approach for the current test effort consisted of the following key steps. These steps and their associated terminology and concepts are discussed in greater detail below.

1. Segment vehicle operating data into trips, where trips are defined as the period between key-on and key-off events.
2. Characterize each trip using several statistical measures, including average speed, distance, and time.
3. Identify common modes of vehicle operation and associate each trip with a mode of operation.
4. Determine the statistical average profile for each operating mode. Then select actual trip data for each mode of operation that are statistically the most representative of the average data set for each mode.
5. Assemble modal trip data (creep, low speed transient, etc.) to create a duty cycle (speed v. time plot) that represents a "cargo move" for each region of operation identified in Section 2.

Segmentation of Trip Data – The segmentation of data into trips as described in step 1, above, was accomplished by the operation of the data collection system. Because the system saves discrete files every time the truck ignition is turned off, each file represents a trip and no further separation is required.

Characterization of Trips - Due to the number of trips and amount of data recorded (approximately 1,258 trips and 1.65 million data points in total), data were loaded into a SQL database for processing. The database calculates ten statistical measures for each trip, as shown in Table 4 below. All parameters other than total duration, non-idle duration, and percentage of time at idle were calculated after removing data points with zero vehicle speed (idling).

Table 4. Statistical Parameters Calculated for each Trip.

Trip Parameter	Units
Average Vehicle Speed	MPH
Maximum Vehicle Speed	MPH
Total Duration	Seconds
Non-idle Duration	Seconds
Percentage of Time at Idle	%
Total Engine Output Energy	HP-hr
Average Engine Speed	RPM
Number of Stops	None
Total Distance	Miles
Engine Output Energy per Mile	HP-hr/mile

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[6] Gautam et. al. *Development and Initial Use of a Heavy-Duty Diesel Truck Test Schedule for Emissions Characterization*, SAE Technical Paper 2002-01-1753, 2002

Identification of Common Operating Modes – A “mode” of operation is a characterized by certain driving behaviors, usually as a result of similar driving conditions. For example, “Creep” mode is typically considered to be associated with vehicle operation in queue lanes. This mode is typified by long periods of idle, interrupted by brief accelerations and decelerations as the truck moves forward in a queue lane. The most common modes of operation and their characteristics vary between vocations; e.g. common operating modes in a vocation like long-haul trucking are likely to be different from the common modes of operation in drayage. Therefore, the trip data must be analyzed to identify modes of operation specific to drayage operation and each trip associated with a particular mode of operation.

In this testing effort, trip modes were identified by comparing the various statistical parameters identified in Table 4, above. After comparing the relationship of each parameter, it was determined that plotting maximum speed versus average speed for each trip tended to separate trips into one of four regions, as shown in Figure 2. Each region was then associated with a particular mode of operation and named based on the type of operation the mode appears to represent. The threshold speeds indicated were determined by identifying the natural breaks in the data using engineering judgment.

Creep – Very low speed operation, typical of operation in truck queues.

Low Speed Transient – Low speed operation, typical of on-dock movement.

High Speed Transient –Operation that achieves high peak speeds but does not sustain these speeds. This operation is typical of travel on regional roads, driving in traffic or brief travel on freeways.

High Speed Cruise – High speed operation with sustained high speeds, typical of travel on freeways.

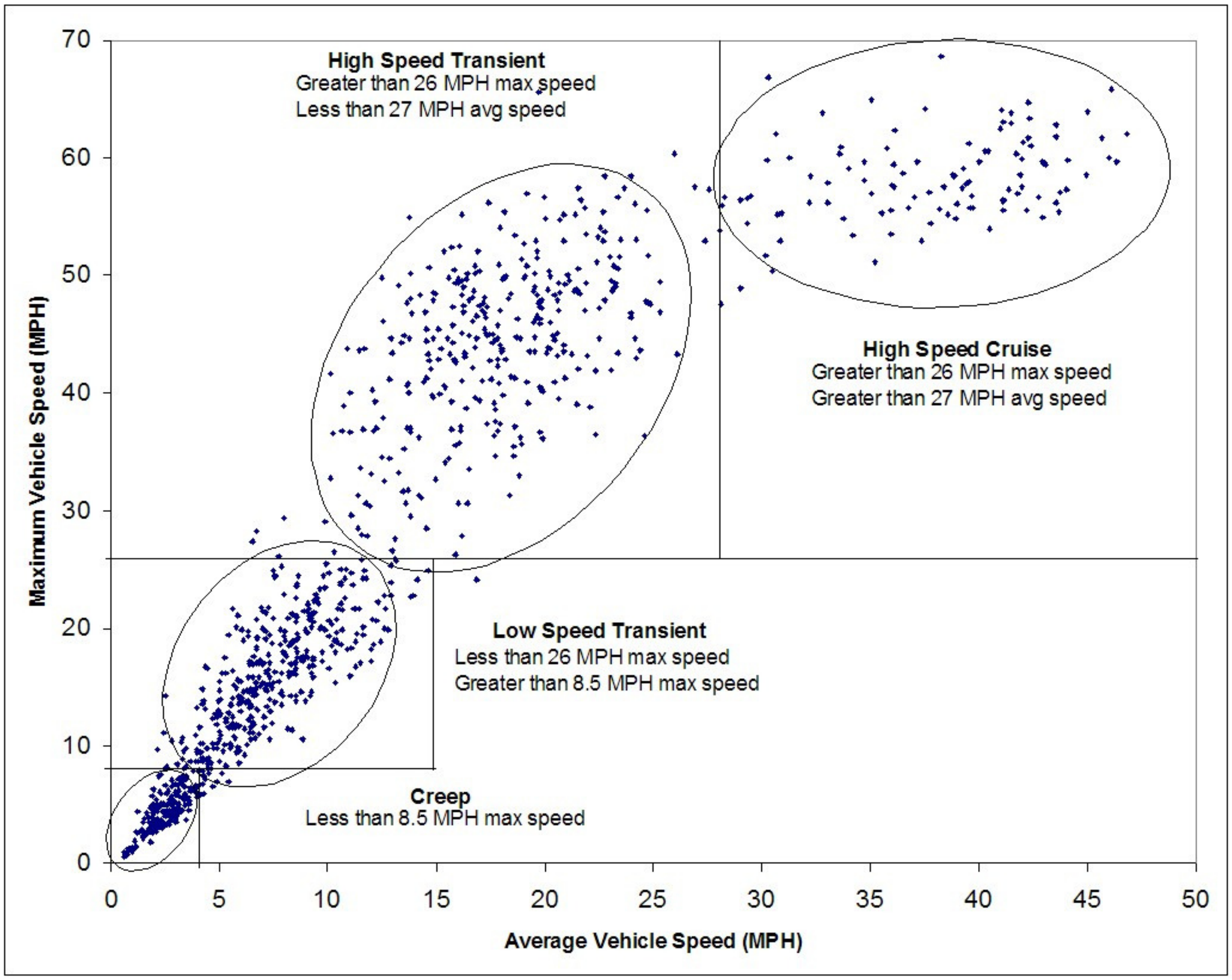

Figure 2. Visualizing the relationship between parameters to identify common operating modes.

Using the metrics of average vehicle speed and maximum trip speed, as described above, each trip was associated with a particular mode of operation. Figure 3 shows the distribution of trips by their associated mode. A subset of trips, those beginning within port boundaries, was then examined. It was determined that the vast majority of Creep and Low Speed Transient data represented queuing or on-dock movements (see Figure 4). Therefore, all cargo moves that represented near-dock, local, or regional drayage operation must be High Speed Transient or High Speed Cruise mode trips. Further, nearly all trips greater than 20 miles in length were identified as High Speed Cruise trips. This meant that while most operating modes could be associated with a particular region of operation, the High Speed Transient mode represented trips from two to twenty miles in length; essentially spanning the near-dock and local haul regions of operation. In order to better characterize near-dock and local haul operations, the High Speed Transient trips were further segmented by trip distance, creating two distinct modes of operation; Short High Speed Transient and Long High Speed Transient. These two modes represent High Speed Transient trips of less than six miles and greater than six miles in length, respectively.

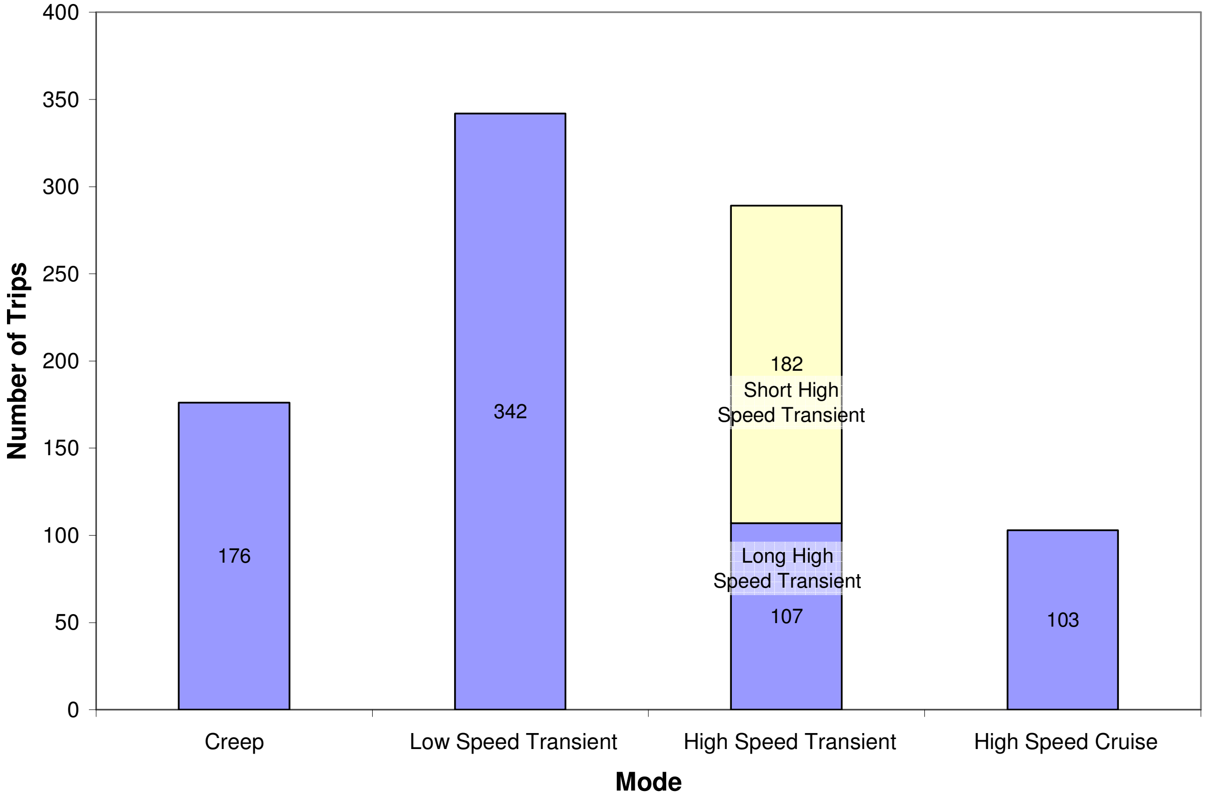

Figure 3. Distribution of trips by associated mode of operation

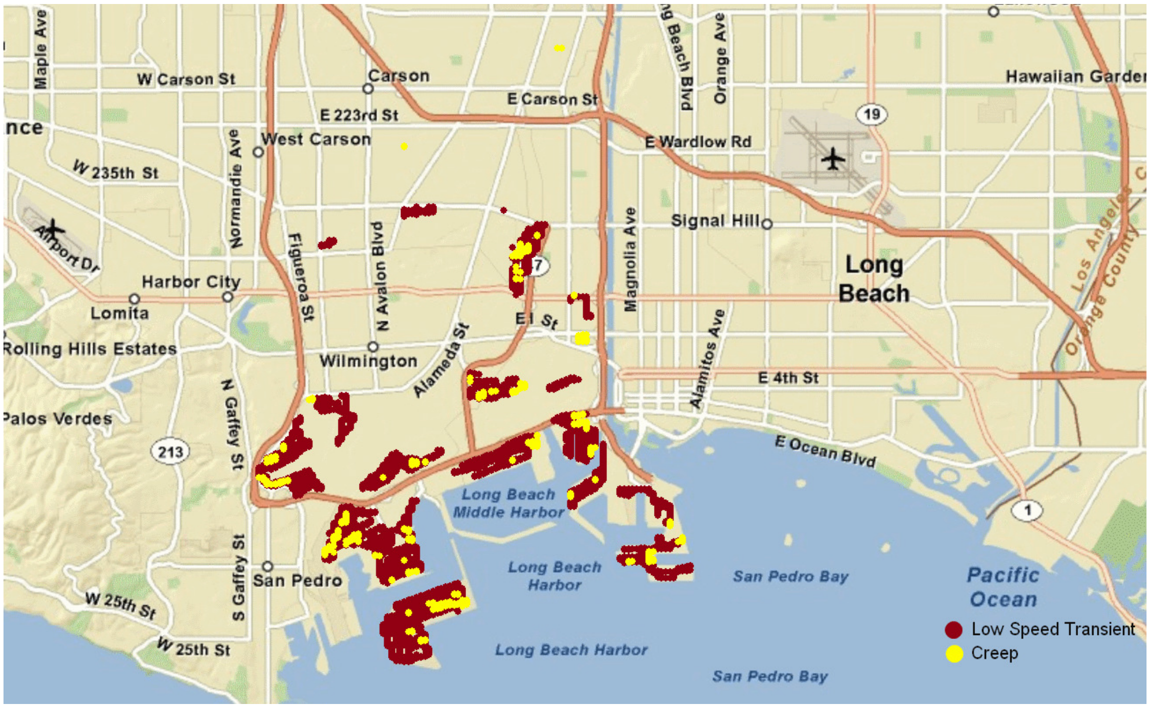

Figure 4. Locations of Creep and Low Speed Transient operation.

Determining Average Profiles and Selecting "Typical Trips" – Once each trip is identified as belonging to a particular mode of operation, an average profile of each mode is calculated. This profile is simply a list of the average value of each parameter (e.g., distance, engine speed, etc). This is done by calculating the average of the parameter for all trips in a particular mode. For example, the average distance of High Speed Cruise operation was determined by averaging the distances of all trips identified as High Speed Cruise trips. Table 5 summarizes the average value of key parameters for each operating mode.

Table 5. Average Values for Key Trip Parameters by Mode of Operation

Mode	Units	Creep	Low Speed Transient	Short High Speed Transient	Long High Speed Transient	High Speed Cruise
Avg. Vehicle Speed	MPH	2.7	7.6	17.1	18.7	37.9
Max. Vehicle Speed	MPH	4.8	16.5	41.3	47.7	58.6
Non-idle Duration	seconds	44	268	890	2,117	4,767
PercentageTime at Idle	none	66%	40%	29%	27%	13%
Stops	none	3.2	8.5	16.2	29	22.7
Distance	miles	0.034	0.58	4.2	11.3	50.6
Energy per Mile	HP-hr/mile	8.4	4.8	3.7	3.8	3.9

Having defined the average parameters for each mode of operation, trips may be ranked by how closely they match the mode averages. Because each mode is described by several parameters, a weighted mean system error was calculated for each trip as compared to the mode averages. Mean system error (MSE) is described by the following equations:

$$MSE = \sum_{n} \frac{\left|(p_i - \overline{p}_i)\right|}{\overline{p}_i} * w_i$$

$$w_i = \frac{\sigma_{\max}}{\overline{p}_i} \Big/ \frac{\sigma_i}{\overline{p}_i}$$

$where:$

$\overline{p}_i$ *is the parameter average value*

p_i *is the trip value of the parameter*

n is the number of parameters

w_i *is the parameter weighting*

A small mean system error indicates that the selected trip is close to the average profile of the mode. While there is no limit on the number of parameters that can be used to create the mode profiles, judicious selection of parameters is still important. First, because the MSE sums the errors of each parameter from the mode average, increasing the number of parameters in the profile will generally increase the MSE. Second, using parameters that duplicate certain physical measures of the profile (e.g. Percentage of Idle, Total Duration, and Non-Idle Time) will result in overly weighting the impact of these physical measures. Therefore, it is best to select a few parameters that represent different physical characteristics of the vehicle operation. Based on these considerations, MSE was calculated for each trip using Average Vehicle Speed, Maximum Vehicle Speed, Energy per Mile, Distance, and Stops. The trip with the smallest MSE in each mode of operation was then selected at the most representative trip for that mode of operation. Table 6 summarizes the average profiles for each trip mode and the profile of the trip that best fits each mode. The relative percentage of the "Best Fit Trip" parameters compared to the mode profile parameters is presented graphically in Figure 5.

Table 6. Average Mode Profiles and Best Fit Trip Statistics for each Operating Mode.

Mode	Avgerage Speed (MPH)	Maximum Speed (MPH)	Energy per Mile (HP-hr/mile)	Distance (miles)	Stops
Creep	2.65	4.81	8.41	0.03	3.24
Best Fit Trip	2.5	4.9	9.1	0.03	3
percentage of mode profile parameter	**96%**	**102%**	**109%**	**84%**	**92%**
Low Speed Transient	7.64	16.47	4.79	0.58	8.54
Best Fit Trip	6.7	17	4.9	0.59	10
percentage of mode profile parameter	**88%**	**103%**	**102%**	**102%**	**117%**
Short High Speed Transient	17.09	41.33	3.75	4.18	16.18
Best Fit Trip	15.3	40.6	3.7	4.99	16
percentage of mode profile parameter	**90%**	**98%**	**99%**	**119%**	**99%**
Long High Speed Transient	18.74	47.67	3.83	11.29	29.00
Best Fit Trip	19.6	46.5	4.2	8.09	27
percentage of mode profile parameter	**105%**	**98%**	**110%**	**72%**	**93%**
High Speed Cruise	37.93	58.59	3.91	50.59	22.71
Best Fit Trip	38.9	58.5	3.5	48.40	19
percentage of mode profile parameter	**102%**	**100%**	**89%**	**96%**	**84%**

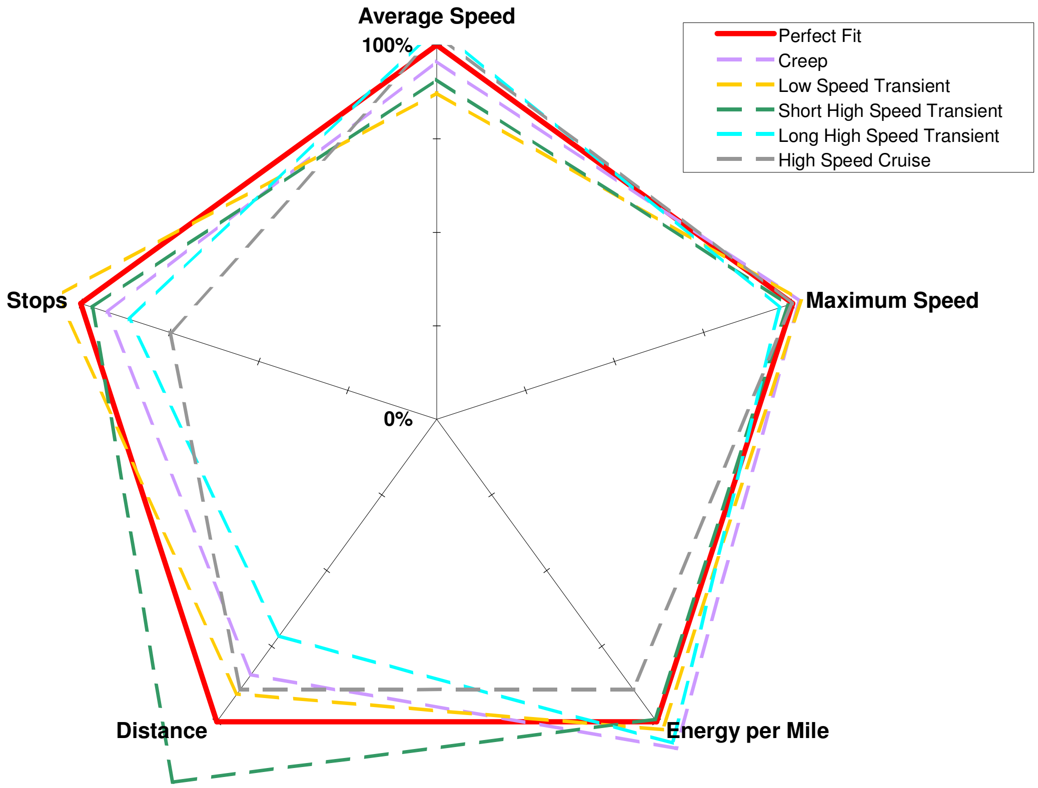

Figure 5. Comparison of "best fit" trip parameters by mode

Assemble Modal Data – In determining the typical duty cycle for drayage operations, it is important to recognize that a drayage move is distinct from a trip in this analysis. A trip is a single block of truck activity between key-on and key-off events. A complete drayage move may, and usually does, involve more than one trip (key-on/key-off event). Conceptually, a drayage move can be separated into 1) on-dock activity followed by 2) transport of the cargo to an off-dock location, a "cargo transport trip." As described previously in this report, an analysis of trips originating within port boundaries shows that nearly all creep and low-speed transient trips are confined to on-dock movement. They are also predominantly less than two miles in length. Figure 6 summarizes the distribution of trips by length and mode; as shown, each region of operation is dominated by a single mode of operation. Specifically, near-dock, local, and regional operations are predominately Short High Speed Transient, Long High Speed Transient, and High Speed Cruise modes respectively. Therefore, when constructing a typical duty cycle for a drayage move, the duty cycle should consist of some Creep and Low Speed Transient operation prior to the High Speed Transient or Cruise operation that is responsible for the majority of the distance of the cargo move.

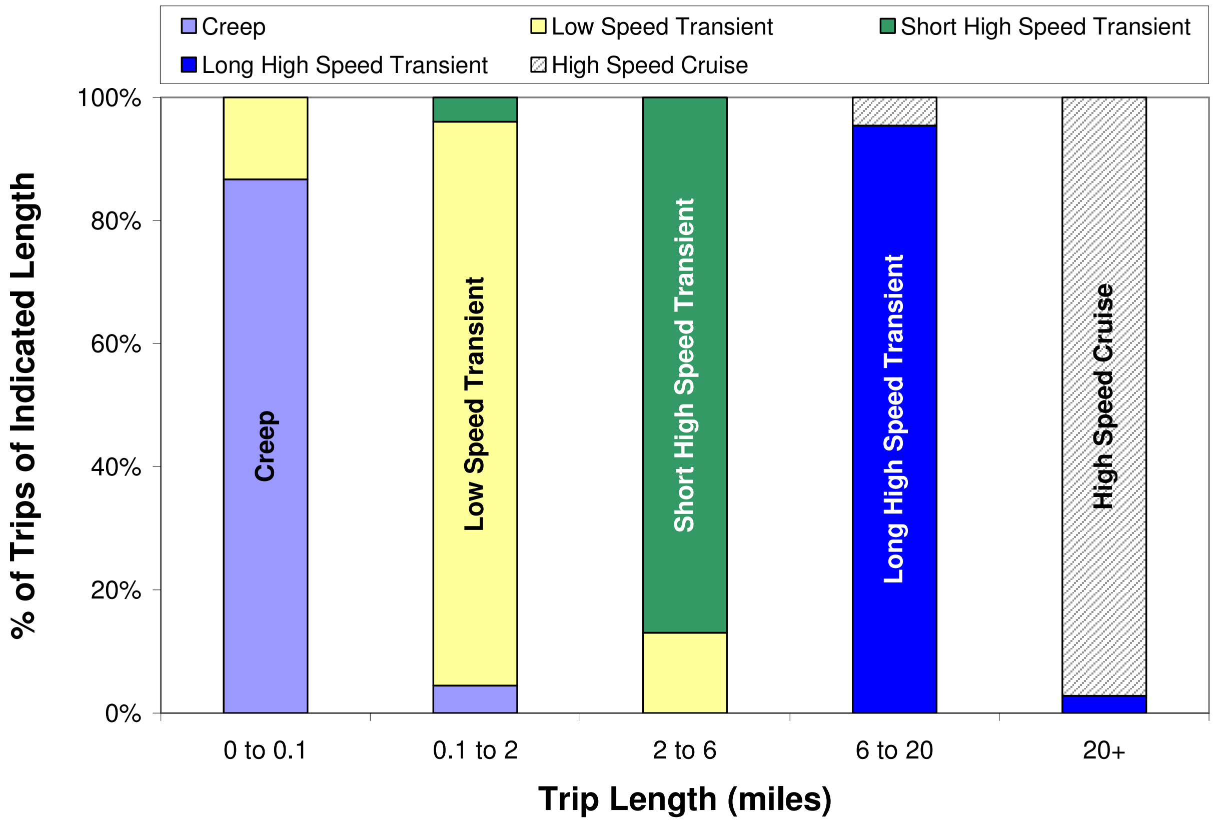

Figure 6. Distribution of modes of operation by trip length for trips originating within port boundaries.

Table 7 provides the number of trips by mode, for trips originating within port boundaries. As shown, there is approximately 1.2 Low Speed Transient trips for each cargo transport trip. This implies that, on average, each trip of two miles or greater in length that originates from the ports is preceded by a Low Speed Transient trip. Similarly, approximately 0.6 Creep trips precede a cargo transport trip. Note that, in practice, it is not possible to have a fraction of a trip. Therefore, when assembling modal data, an entire Creep and Low Speed Transient trips should be incorporated into the duty cycle. Figure 7 illustrates the precedence of a High Speed Cruise trip by Creep and Low Speed Transient trips.

Table 7. Number of Trips Originating within Port Boundaries by Mode

	On-dock Maneuvers		Cargo Transport		
Mode	**Creep**	**Low Speed Transient**	**Short High Speed Transient**	**Long High Speed Transient**	**High Speed Cruise**
Number of Trips	120	203	76	58	30
			Total Cargo Transport trips: 164		
On-dock Trip/ Cargo Transport Trip	**0.7**	**1.2**			

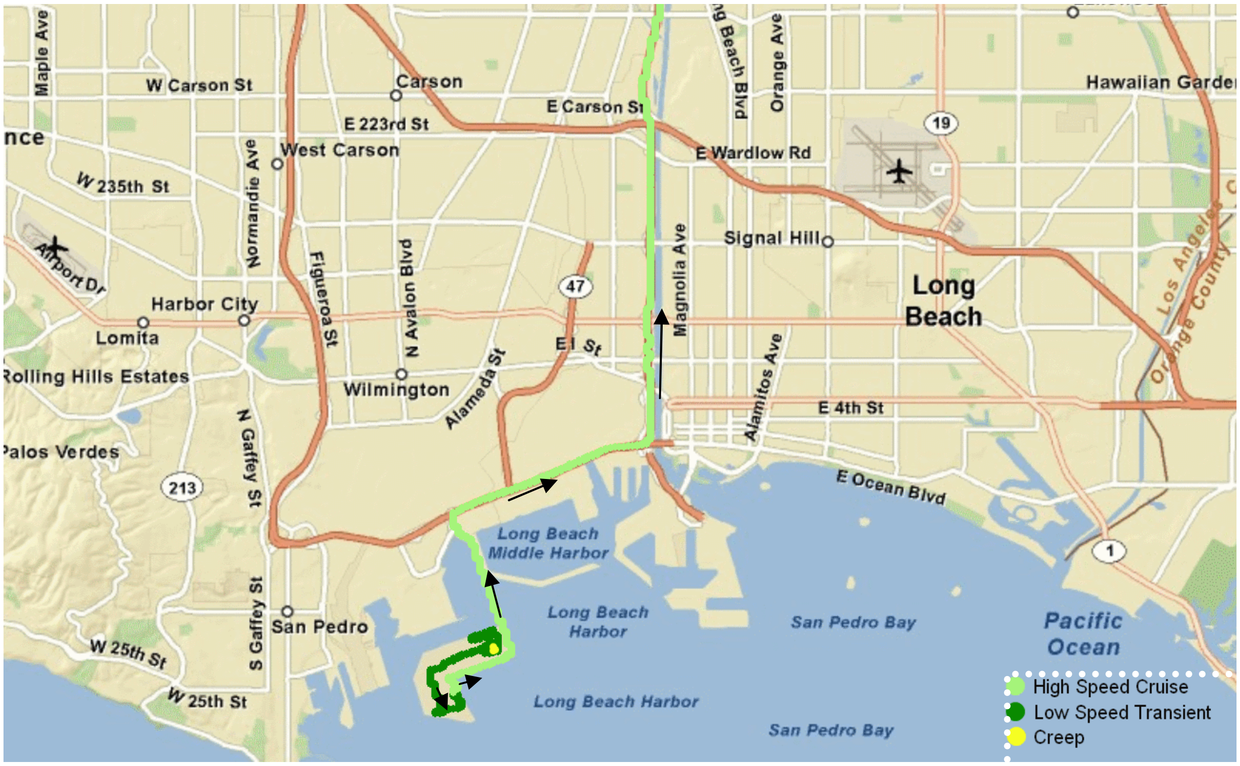

Figure 7. High Speed Cruise trip preceded by a Low Speed Transient trip.

5.0 Results

Using the data analysis method described above, three duty cycles are constructed. Each duty cycle consists of a high speed mode (either Transient or Cruise) preceded by one Creep-mode and one Low Speed Transient mode trip. In all cases, the same Creep and Low Speed Transient trips are used and these are the best-fit trips identified previously. Based on the distribution of trips by trip length and mode, as shown in Figure 6, duty cycles are constructed using the following best-fit trip data:

1. Near-dock (2 to 6 miles) – Creep → Low Speed Transient → Short High Speed Transient
2. Local (6 to 20 miles) - Creep → Low Speed Transient → Long High Speed Transient
3. Regional (20+ miles) - Creep → Low Speed Transient → High Speed Cruise

Figure 10, Figure 11, and Figure 12 depict the resulting duty cycles for near-dock, local, and regional operations respectively. Table 8 summarizes key statistics for each of the synthesized duty cycles. In addition to the statistics for the synthesized duty cycles, statistics for modes of operation are provided. Note that Table 6 provides average values for each mode of operation as well as the best fit trip data with idle data filtered out. While this information is useful to identify best-fit trip data, idle is an inherent part of drayage operation and should be included in aggregate statistics. Table 9 provides statistical measures for all trips in each mode, as well as the data set as a whole.

Table 8. Duty cycle statistics

Statistic	Units	Near Dock	Local	Regional
Duration	seconds	3,049	4,643	6,167
Average Speed	MPH	6.6	6.8	28.6
Maximum Speed	MPH	40.6	46.5	58.5
Distance	miles	5.61	8.71	49.02
Stops		30	40	34
Miles/Stop		0.19	0.22	1.44
Max. Acceleration	MPH/sec	4.45	3.45	6.65
Max. Deceleration	MPH/sec	-5.35	-4.10	-7.30
% Idle	%	50%	60%	22%

Port Bridge Crossings

Three key bridges within the port complex are heavily utilized by drayage trucks. These are the Gerald Desmond, Heim, and Vincent Thomas bridges. Each bridge has approach grades of 5-6.5% that vary in overall length. The Gerald Desmond Bridge has been identified as having a particularly challenging combination of approach grade and length when travelling eastbound. Therefore, an analysis of vehicle speed and horsepower data was conducted for eastbound transits across the Gerald Desmond Bridge to serve as a high-end estimate of the engine power typically used to transit the port bridges. Figure 8 shows an example of the engine horsepower versus time for a truck making an eastbound crossing of the Gerald Desmond Bridge. The figure clearly shows the high power demand required as the truck climbs the bridge. The power demand then rapidly decreases to zero as the truck crests the bridge and travels downhill. A typical transit across the bridge takes approximately 60 seconds, with more than half the time associated with climbing the bridge.

Figure 9 provides a distribution of the recorded engine power data for all data points associated with eastbound crossings of the Gerald Desmond Bridge where the truck was travelling at greater than 20 miles per hour. Data were filtered based on vehicle speed to remove data points associated truck activity near, but not on, the bridge. For example, trucks operating on Pier T, D, and E that may pass under the bridge will register GPS locations that appear to be on the bridge.

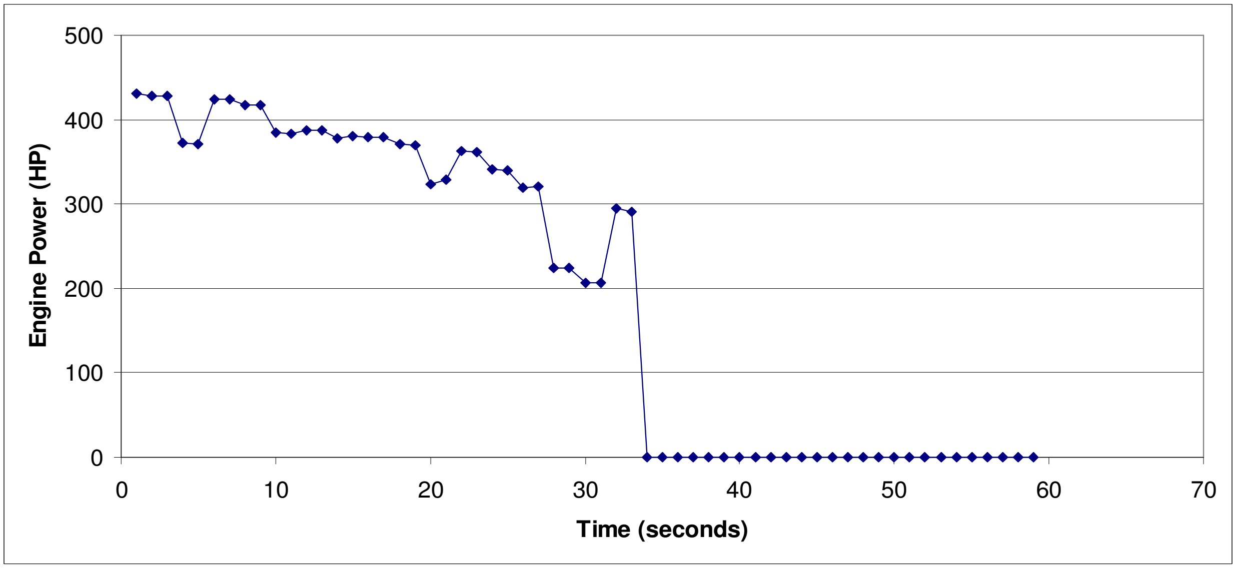

Figure 8. Example of engine power during an eastbound crossing of the Gerald Desmond Bridge.

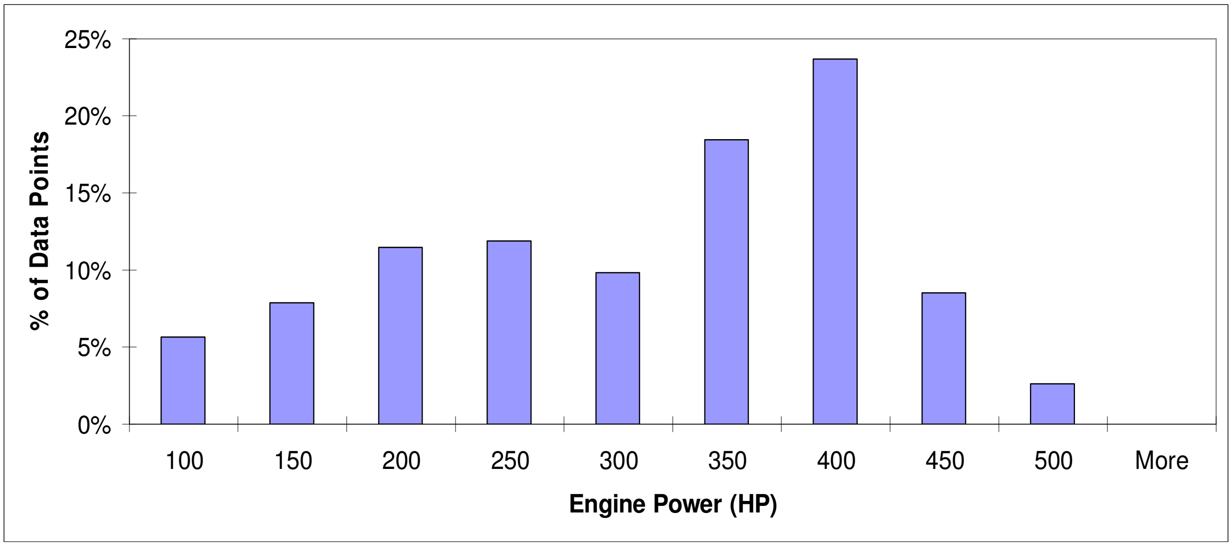

Figure 9. Distribution of engine power data for eastbound crossings of the Gerald Desmond Bridge.

Usage of Duty Cycles in Dynamometer Testing

One anticipated use of the duty cycles presented in this report is the production of emissions and fuel economy estimates for advanced technology vehicles through dynamometer testing. While the data used to create the duty cycles are real world truck activity data, there are several potential issues to consider when attempting to replicate these duty cycles in dynamometer tests.

1. Vehicle weight – The combined weight of the truck, container chassis, and container, known as the gross combined weight (GCW), was not available in the data collected during the testing. Therefore, the actual GCW for each mode of operation cannot be determined. It is recommended that an average GCW be estimated for dynamometer testing. Most drayage trucks are Class 8 vehicles registered to haul a GCW of 80,000 lbs. However, due to a variety of issues with loading a truck safely to its maximum weight, most drayage trucks are loaded to less than 80,000 lbs. The Federal Highway Administration estimates that a typical 5-axle semi-truck is loaded to approximately 65,000 lbs GCW[7]. Therefore, it is recommended that a test weight of 65,000 lbs be used as an average loaded weight. A weight of 80,000 lbs should be used as a maximum test weight.
2. Trace gradients – As previously mentioned, the vehicle speed data used to construct the duty cycles are real world data. Therefore it is not beyond the capability of a test truck to replicate the vehicle speed traces (vehicle speed vs. time charts in the figures below) on a dynamometer. In practice however, it can be very difficult to replicate sections of the speed trace that change rapidly (high gradient regions). In part, this is simply a limitation of the human driver's ability to follow a trace with such rapid changes in vehicle speed. Additionally, rapid accelerations and decelerations can be difficult or impossible to reproduce on many dynamometers because they may damage the dynamometer. The duty cycles presented in this report may need to be filtered or smoothed to reduce trace gradients to acceptable levels for the dynamometer facility conducting the testing.
3. Test duration – The duty cycles presented in this report range in duration from 2,300 to 7,200 seconds. While this is representative of actual drayage operation, long tests increase the chance for dynamometer testing errors due to driver fatigue and greater aggregation of emissions data from small deviations from the test cycle. Somewhat more practical duty cycles may be created by reducing periods of significant idle and, in the case of the Regional Haul duty cycle, reducing the duration of the cruise portion of the test.

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[7] Table III-4, Comprehensive Truck Size and Weight Study, 2000. Federal Highway Administration.

6.0 Recommendations

The Port of Long Beach and Port of Los Angeles continue to support the development and deployment of clean, advanced drayage trucks through their Technology Advancement Program. Based on the ports' joint goal to support the development of these advanced vehicles, TIAX makes the following recommendations:

1. Make available the results of this report, including the detailed drive cycle data, to interested developers of low emission vehicle technologies.
2. Produce useable dynamometer test cycles for near-dock, local, and regional drayage operations by:
    a. Performing a statistical analysis of existing chassis test cycles to identify any test cycles that may be sufficiently similar to the five modes of operation identified in this report, that the existing test cycles could be used in place of the real world data presented here.
    b. Filter and scale the real-world duty cycle data to produce dynamometer test cycles that comply with the limitations of current chassis dynamometer laboratories.
    c. Examine average loaded and empty cargo container weights to determine reasonable dynamometer test weights.

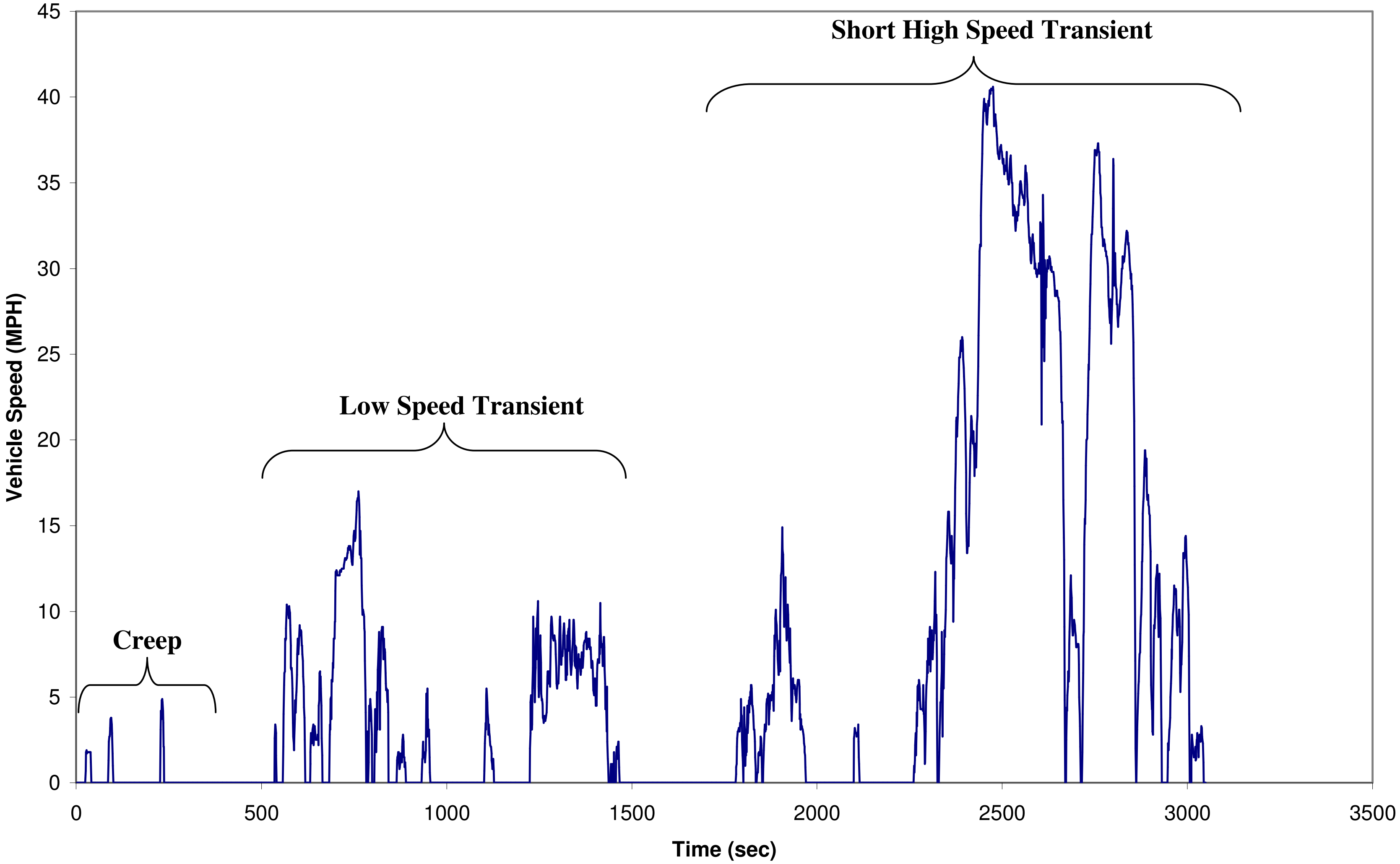

Figure 10. Near-dock duty cycle

Time series data for each mode are provided in the attached file “Modal Speed vs Time Data.xls”

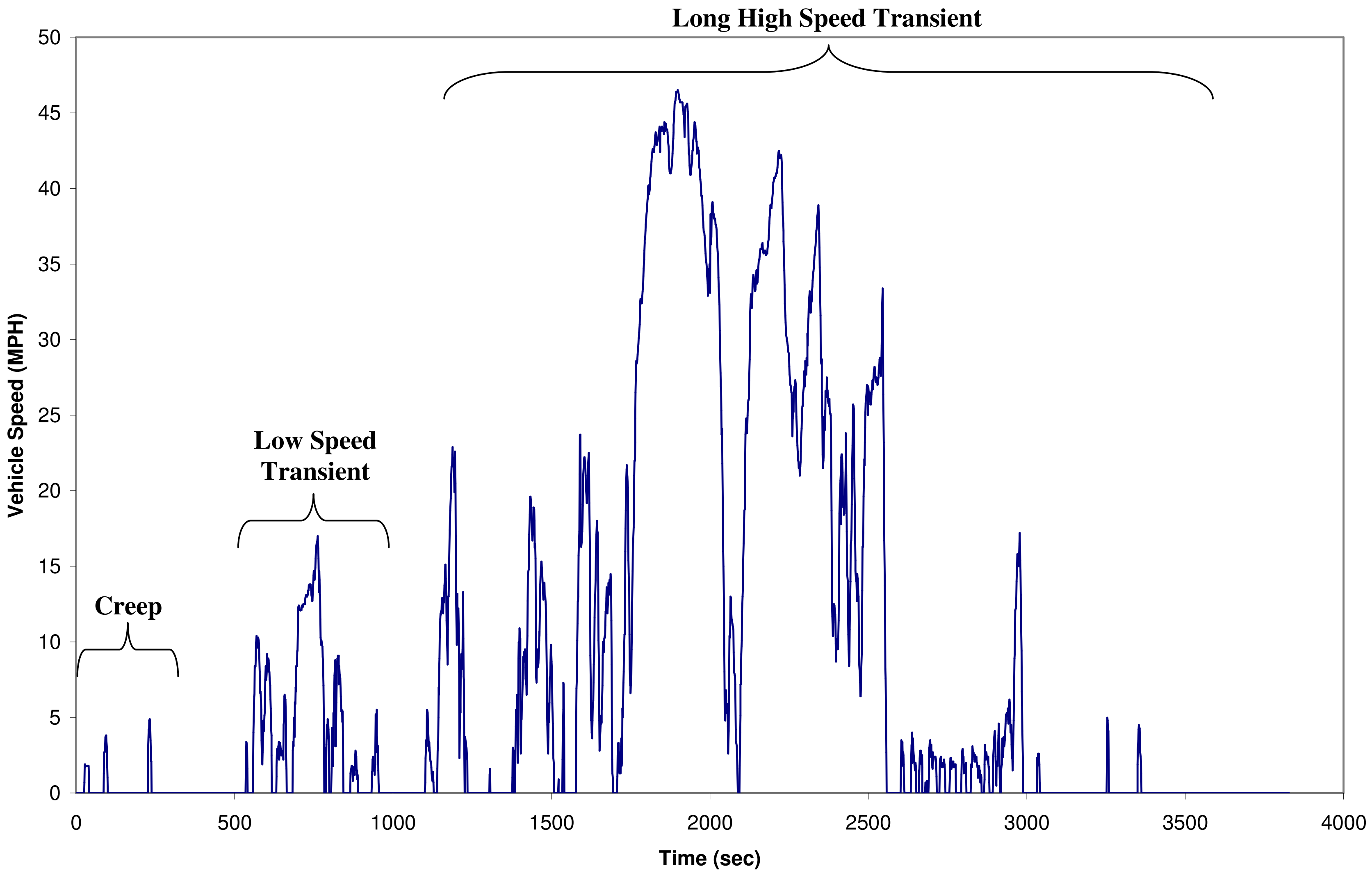

Figure 11. Local Haul duty cycle

Time series data for each mode are provided in the attached file "Modal Speed vs Time Data.xls"

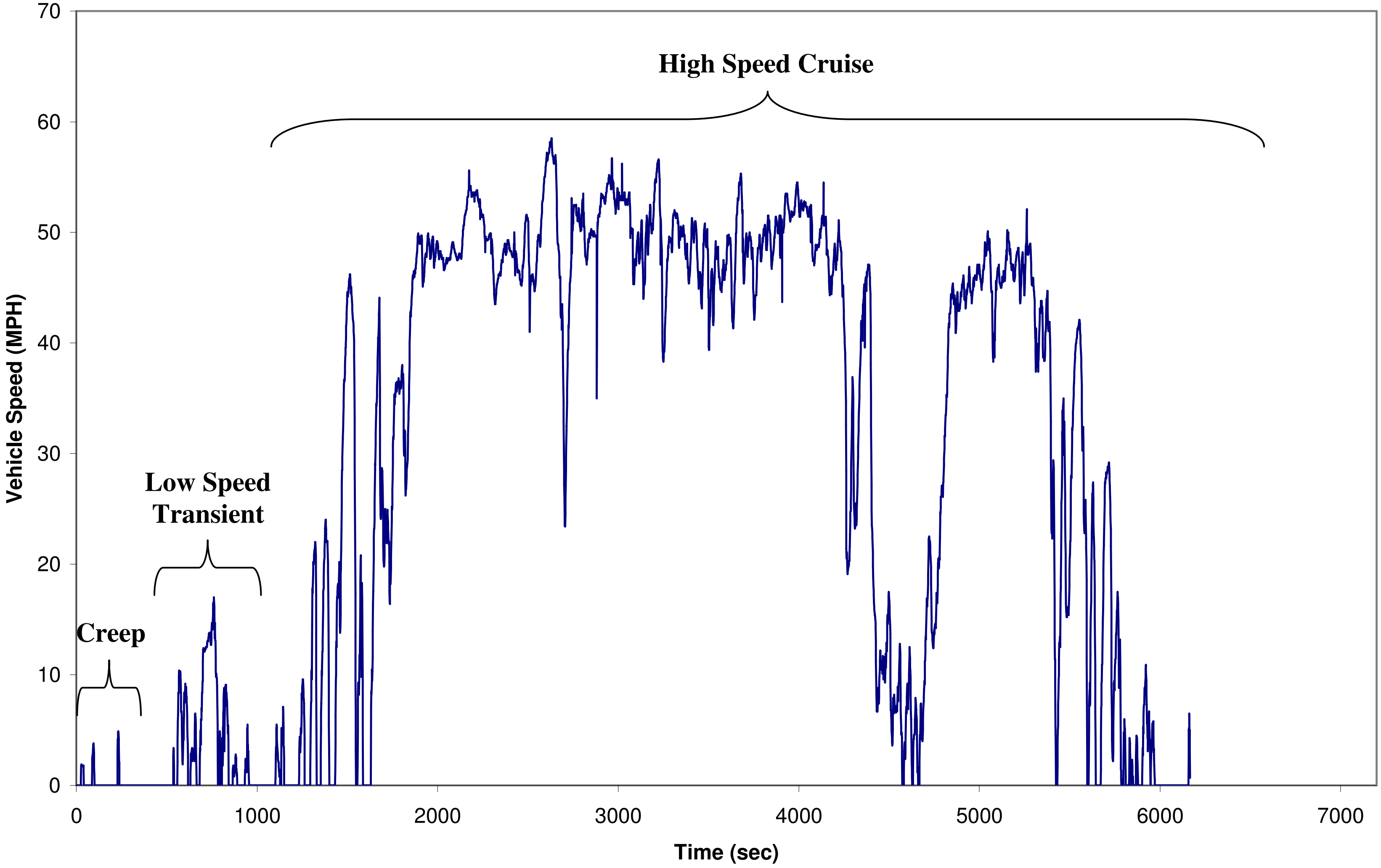

Figure 12. Regional Haul duty cycle

Time series data for each mode are provided in the attached file “Modal Speed vs Time Data.xls”

Table 9. Summary of parameter values for various modes of operation.

Mode	Parameter	Average	Maximum	Standard Deviation
Creep	Average Vehicle Speed	0.8	4.1	0.9
	Average Speed ex-Idle	2.7	5.9	1.0
	Maximum Vehicle Speed	4.8	8.5	1.9
	Average Horsepower	14.4	47.8	6.7
	Average Horsepower ex-Idle	20.2	50.4	9.1
	Maximum Horsepower	74.8	262.6	43.2
	Total Time	363	2,036	411
	Engine Energy Output	1.2	23.9	2.1
	Engine Energy Output ex-Idle	0.3	1.8	0.3
	Stops	3.3	9.0	3.5
	Trip Length	0.03	0.29	0.04
	Miles/Stop	0.01	0.11	0.02
	Engine Energy Output per Mile	478	71,811	5,409
	Engine Output per Mile ex-Idle	8.4	31.5	4.4
	% Idle	66.2%	99.90%	28.2%
Low Speed Transient	Average Vehicle Speed	4.3	16.2	2.7
	Average Speed ex-Idle	7.6	16.9	2.5
	Maximum Vehicle Speed	16.5	25.9	4.5
	Average Horsepower	25.2	162.4	12.4
	Average Horsepower ex-Idle	35.3	76.9	11.4
	Maximum Horsepower	192.7	485.4	184.6
	Total Time	592	2,816	509
	Engine Energy Output	3.7	14.7	2.9
	Engine Energy Output ex-Idle	2.7	11.4	2.3
	Stops	8.5	9.0	8.3
	Trip Length	0.58	3.38	0.50
	Miles/Stop	0.11	0.82	0.13
	Engine Energy Output per Mile	8.0	110.2	7.9
	Engine Output per Mile ex-Idle	4.8	12.1	1.3
	% Idle	39.9%	94.1%	24.5%

Note: “ex-idle” denotes values calculated after removing data points where the vehicle speed is zero.

Mode	Parameter	Average	Maximum	Standard Deviation
Short High Speed Transient	Average Vehicle Speed	12.1	24.6	4.3
	Average Speed ex-Idle	17.1	26.1	3.8
	Maximum Vehicle Speed	41.3	55.8	7.1
	Average Horsepower	47.4	105.3	15.9
	Average Horsepower ex-Idle	62.6	136.2	18.7
	Maximum Horsepower	344.6	493.3	78.4
	Total Time	1,385	4,008	687
	Engine Energy Output	17.2	40.5	8.3
	Engine Energy Output ex-Idle	15.7	36.9	7.7
	Stops	16.2	9.0	9.6
	Trip Length	4.18	5.93	1.50
	Miles/Stop	0.34	1.25	0.21
	Engine Energy Output per Mile	4.2	9.8	1.3
	Engine Output per Mile ex-Idle	3.7	7.7	1.0
	% Idle	29.0%	79.8%	15.4%
Long High Speed Transient	Average Vehicle Speed	13.7	23.7	4.3
	Average Speed ex-Idle	18.7	26.9	3.7
	Maximum Vehicle Speed	47.7	60.4	5.2
	Average Horsepower	54.2	106.3	16.2
	Average Horsepower ex-Idle	70.5	114.8	19.4
	Maximum Horsepower	389.2	494.4	79.7
	Total Time	2,956	11,428	2,096
	Engine Energy Output	46.1	240.2	46.3
	Engine Energy Output ex-Idle	43.0	236.5	45.1
	Stops	29.0	93.0	16.6
	Trip Length	11.29	54.93	11.64
	Miles/Stop	0.43	1.92	0.30
	Engine Energy Output per Mile	4.2	7.2	1.2
	Engine Output per Mile ex-Idle	3.8	6.8	1.1
	% Idle	27.2%	68.9%	13.2%

Note: "ex-idle" denotes values calculated after removing data points where the vehicle speed is zero.

Mode	Parameter	Average	Maximum	Standard Deviation
High Speed Cruise	Average Vehicle Speed	32.9	45.3	6.4
	Average Speed ex-Idle	37.9	46.8	5.1
	Maximum Vehicle Speed	58.6	74.3	4.5
	Average Horsepower	129.6	242.7	36.7
	Average Horsepower ex-Idle	147.9	246.6	38.2
	Maximum Horsepower	457.3	499.7	44.6
	Total Time	5,577	14,816	2,540
	Engine Energy Output	199.8	454.7	91.7
	Engine Energy Output ex-Idle	197.2	447.7	90.7
	Stops	22.7	9.0	16.9
	Trip Length	50.59	131.79	22.43
	Miles/Stop	3.17	13.03	2.36
	Engine Energy Output per Mile	4.0	5.7	0.9
	Engine Output per Mile ex-Idle	3.9	5.7	0.9
	% Idle	13.3%	39.8%	8.1%
Full Data Set	Average Vehicle Speed	9.5	45.3	10.2
	Average Speed ex-Idle	13.3	46.8	10.9
	Maximum Vehicle Speed	27.7	74.3	19.1
	Average Horsepower	42.8	242.7	38.0
	Average Horsepower ex-Idle	54.7	246.6	41.7
	Maximum Horsepower	253.5	499.7	177.4
	Total Time	1,550	14,816	2,041
	Engine Energy Output	33.1	454.7	70.4
	Engine Energy Output ex-Idle	31.6	447.7	69.7
	Stops	13.1	93.0	13.4
	Trip Length	8.1	131.8	17.8
	Miles/Stop	0.52	13.03	1.25
	Engine Energy Output per Mile	97	71,811	2,381
	Engine Output per Mile ex-Idle	5.1	31.5	2.8
	% Idle	38.3%	99.9%	26.6%

Note: “ex-idle” denotes values calculated after removing data points where the vehicle speed is zero.