

Heavy-Duty Vehicle Port Drayage Drive Cycle Characterization and Development

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ABSTRACT

In an effort to better understand the operational requirements of port drayage vehicles and their potential for adoption of advanced technologies, National Renewable Energy Laboratory (NREL) researchers collected over 36,000 miles of in-use duty cycle data from 30 Class 8 drayage trucks operating at the Port of Long Beach and Port of Los Angeles in Southern California. These data include 1-Hz global positioning system location and SAE J1939 high-speed controller area network information. Researchers processed the data through NREL's Drive-Cycle Rapid Investigation, Visualization, and Evaluation tool to examine vehicle kinematic and dynamic patterns across the spectrum of operations. Using the k-medoids clustering method, a repeatable and quantitative process for multi-mode drive cycle segmentation, the analysis led to the creation of multiple drive cycles representing four distinct modes of operation that can be used independently or in combination. These drive cycles are statistically representative of real-world operation of port drayage vehicles. When combined with modeling and simulation tools, these representative test cycles allow advanced vehicle or systems developers to efficiently and accurately evaluate vehicle technology performance requirements to reduce cost and development time while ultimately leading to the commercialization of advanced technologies that meet the performance requirements of the port drayage vocation. The drive cycles, which are suitable for chassis dynamometer testing, were compared to several existing test cycles. This paper presents the clustering methodology, accompanying results of the port drayage duty cycle analysis and custom drive cycle creation.

CITATION: Prohaska, R., Konan, A., Kelly, K., and Lammert, M., "Heavy-Duty Vehicle Port Drayage Drive Cycle Characterization and Development," *SAE Int. J. Commer. Veh.* 9(2):2016, doi:10.4271/2016-01-8135.

INTRODUCTION AND BACKGROUND

The DOE's U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is the only research laboratory solely dedicated to the research and development of energy efficiency and renewable energy technologies. As part of its mission, NREL's Fleet Test & Evaluation (FT&E) group, funded by the DOE's Vehicle Technologies Office within the Vehicle & Systems Simulation and Testing Activities, works in partnership with commercial and government fleets and industry partners to evaluate the performance of alternative fuels and advanced technologies in medium- and heavy-duty fleet vehicles.

One way to evaluate and compare advanced vehicle technologies is through the use of standard chassis dynamometer test cycles. Another is through the use of modeling and simulation tools running analyses on standard test cycles. Previous testing and analysis conducted by NREL has illustrated the influence of drive cycles on both energy consumption and greenhouse gas emissions [1, 2, 3, 4].

Researchers from NREL's Fleet Test & Evaluation group identified port drayage heavy-duty truck operations as a candidate for further research on the potential fuel savings impact of advanced technologies. Port drayage operation is a unique and specialized

type of goods movement. Drayage refers to the movement of cargo containers, often called intermodal containers, between a port terminal and an inland distribution center or rail yard terminal.



Figure 1. Map of Port of Long Beach and Port of Los Angeles showing 15 container terminals. Eleven have on-dock rail lines. [9, 10]

Due to the varied operational modes inherent in drayage, standard heavy-duty chassis dynamometer tests [5] do not accurately or fully characterize the real-world port drayage duty cycle seen at the San Pedro Port of Los Angeles (POLA) and Port of Long Beach (POLB). The POLA and POLB are located in Southern California in the South Coast Air Quality Management District, which is a nonattainment area for criteria air pollutants as determined by the U.S Environmental Protection Agency’s national ambient air quality standards. Collectively the two ports form the largest and busiest container port in the United States and the fifth busiest in the world [6] with over 15 million twenty-foot equivalent units processed in 2015 [7, 8]. With over 15,000 acres of land and sea under port authority, there are 15 primary container terminals that process the majority of drayage container freight in and out of the ports (Figure 1) with nine in the POLA and six in the POLB.

FIELD DATA COLLECTION

Starting in October 2014, NREL researchers began to collect in-use duty cycle data using data loggers installed on drayage trucks operating at the POLA and POLB. The researchers worked with three different trucking companies to collect a more representative sample of drayage operations. Over 75 channels of data were collected at a 1-Hz sampling rate from the vehicles’ SAE J1939 controller area network bus, along with global positioning system (GPS) data using Isaac Instruments DRU900/908 data logging devices (Figure 2). These standalone data loggers connect to the vehicle’s diagnostic port and do not interfere with vehicle operation.



Figure 2. Isaac DRU908 data logger (Image Courtesy: Isaac Instruments).

In total, 557 days of vehicle operation were recorded from 30 vehicles from various manufacturers, operating at three different companies, totaling 36,444 miles. The vehicles were all configured as Class 8 day cab tractors with a mixture of automatic, automated, and manual transmissions. An example of one of these vehicles is shown in Figure 3. Additional details of the data collection can be seen in Table 1.

The controller area network bus data form the basis for the technical analysis of this paper and are supported by the GPS data, which were used for the identification of each trip’s origin and destination as well as for an additional means to confirm data integrity. An example of the GPS traces collected within the POLA can be seen in Figure 4.



Figure 3. Class 8 diesel tractor operating at the San Pedro ports from which field data were collected.

Table 1. Field Data Collection Summary

Total Mileage	36,444 Miles
Total Hours of Operation	2,809 Hours
Driving days	557 Days
Operating companies	3 Companies
Unique vehicles	30 Vehicles
Vehicle Manufacturers	Navistar, Volvo, Mack, Freightliner, Peterbilt & Sterling



Figure 4. GPS route (shown in red) of drayage truck data collection at the Port of Los Angeles.

After the data loggers were retrieved from the field, the data were downloaded, reviewed, and then securely stored in NREL’s Fleet DNA database which acts as the clearing house for all field deployment data from NREL’s Fleet Test & Evaluation activities [11].

FIELD DATA GEOGRAPHIC ANALYSIS

After the field data were uploaded to the Fleet DNA database, the results were processed using NREL's semi-automated Drive-Cycle Rapid Investigation, Visualization, and Evaluation (DRIVE) processing tool [12]. DRIVE quickly filters large sets of raw data, identifying erroneous data points and missing data sections that may require additional processing routines while outputting summary statistics on over 175 unique drive cycle metrics such as average driving speed, number of stops per mile, maximum speed, etc. These metrics can be used to quantitatively describe daily vehicle operation as well as compare and contrast in-field duty cycles with chassis dynamometer drive cycles.

To better understand the components of port drayage operation, field data were analyzed at the trip level. A trip is defined as the time between "key cycles" or when a vehicle ignition is turned on and when it is turned off. Using the trip data as opposed to daily aggregate statistics better revealed the unique operation of the drayage trucks and offered a clearer picture of how the vehicles operated throughout the day.

Initial analysis was focused on characterizing the different operating modes of drayage operation based on the geography of where trips originated and ended. Researchers hypothesized that the vehicle trip kinematics were highly correlated to the geographic attributes of trip. Four distinct regions and an "other region" (Figure 5) were created to represent the primary locations of drayage trips. All of the trips were then categorized based on the geographic location of their start and stop location into one of the 25 possible groups and a geospatial analysis was run on all of the trip data.

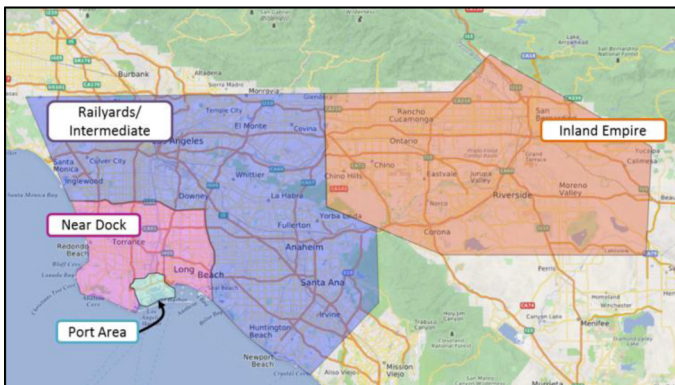


Figure 5. Geographic regions for trip-level origin and destination analysis.

This trip-level geospatial origin and destination analysis indicated that of the possible 25 combinations of start and end locations, 74% of the mileage, 75% of the fuel and 83% of operating time could be accounted for in just six of the combinations (see Table 2) as follows:

- From: Port Area | To: Port Area
- From: Near Dock | To: Near Dock
- From: Port Area | To: Near Dock
- From: Near Dock | To: Port Area
- From: Near Dock | To: Inland Empire
- From: Inland Empire | To: Near Dock

Table 2. Trip level origin and destination statistics

Percent of Total Mileage					
To \ From	Port Area	Near Dock	Rail Yard/Inter.	Inland Empire	Other
Port Area	14.9%	13.7%	1.8%	2.1%	0.0%
Near Dock	12.3%	10.4%	4.6%	12.2%	1.9%
Rail Yard/Inter.	3.3%	3.1%	1.2%	0.7%	0.0%
Inland Empire	3.7%	10.2%	0.7%	1.6%	0.0%
Other	0.5%	0.9%	0.1%	0.1%	0.1%

Percent of Total Fuel Consumed					
To \ From	Port Area	Near Dock	Rail Yard/Inter.	Inland Empire	Other
Port Area	18.1%	14.1%	2.1%	1.9%	0.0%
Near Dock	11.3%	10.5%	4.8%	12.8%	2.0%
Rail Yard/Inter.	2.6%	2.8%	1.6%	0.7%	0.0%
Inland Empire	2.8%	8.3%	0.6%	1.7%	0.0%
Other	0.4%	0.7%	0.0%	0.1%	0.2%

Percent of Total Operating Time					
To \ From	Port Area	Near Dock	Rail Yard/Inter.	Inland Empire	Other
Port Area	28.2%	15.0%	0.9%	0.7%	0.0%
Near Dock	10.6%	20.4%	2.8%	4.5%	0.7%
Rail Yard/Inter.	1.6%	2.0%	3.2%	0.3%	0.0%
Inland Empire	1.3%	4.1%	0.4%	2.4%	0.0%
Other	0.3%	0.3%	0.0%	0.1%	0.2%

Further trip-level drive cycle analysis of the origin and destination method indicated that while the vehicles may start and stop their trips in the same region, the trip activity could vary widely with trip maximum speed and average driving speed as shown in Figure 6.

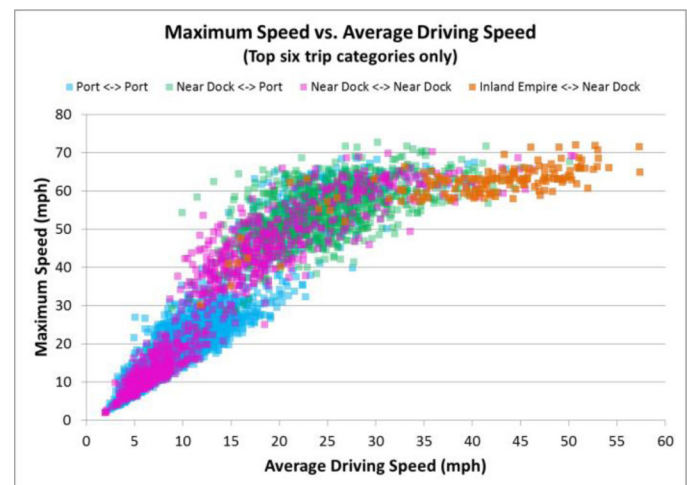


Figure 6. Trip results from the top six categories identified in Table 2.

As more metrics were analyzed, researchers began to see multiple overlapping modes in each of the six selected categories, which showed that although aggregate mileage, fuel use, and operational time could be discretely categorized by trip origin and destination, driving behavior could not.