

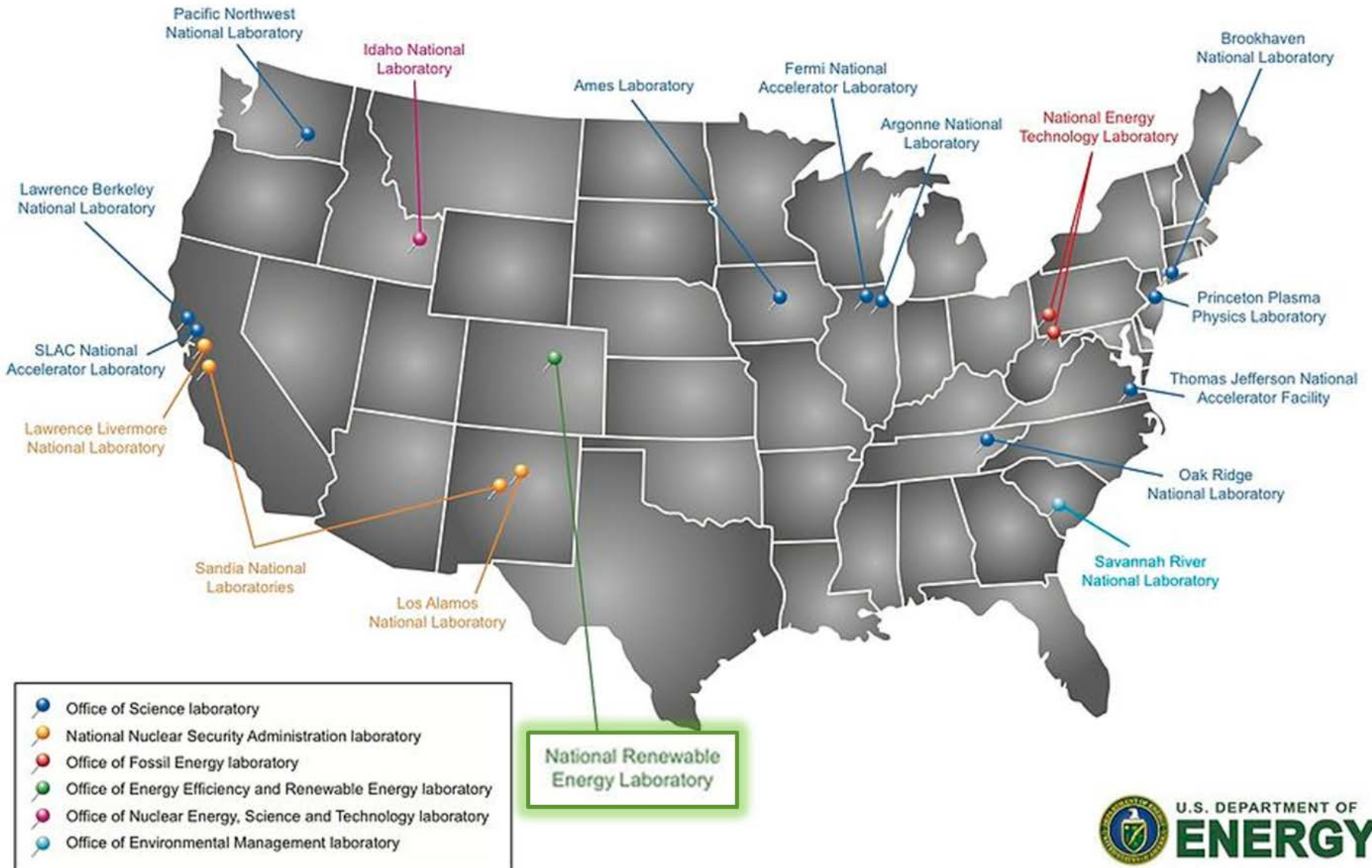
Heavy-Duty Vehicle Port Drayage Drive Cycle Characterization and Development

NREL/PR-5400-67291

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& Michael Lammert

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Engineering Congress
October 4-6, 2016
Rosemont, Illinois, USA

US Department of Energy National Labs



NREL Transportation and Mobility RD&D Activities

Advanced Combustion & Fuels

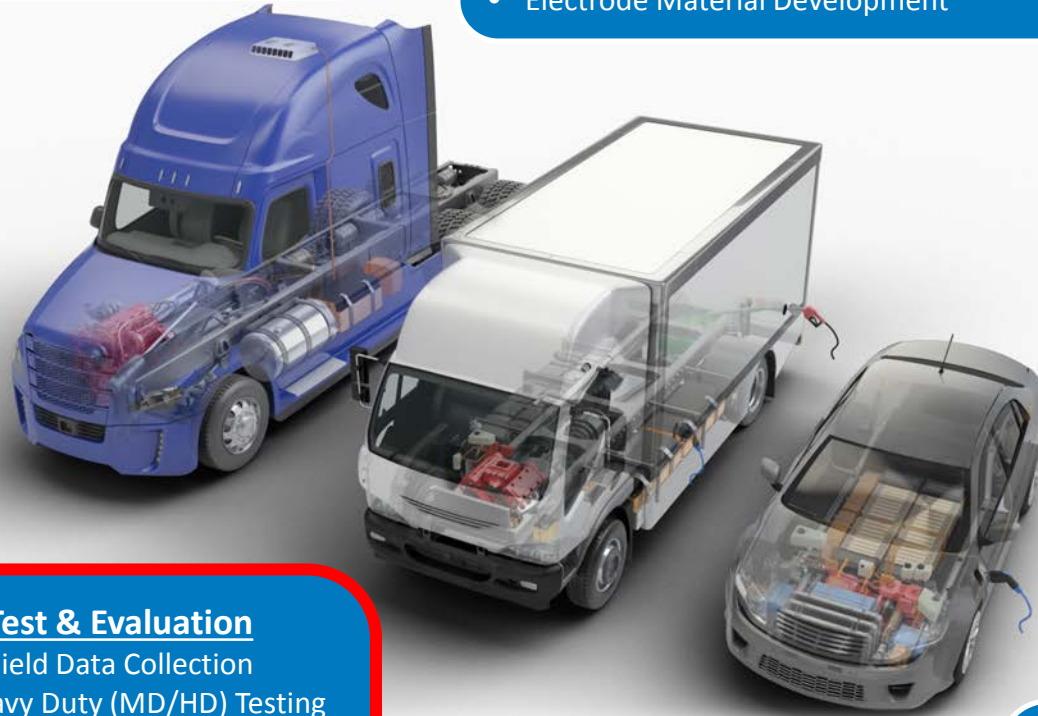
- Advanced Petroleum & Biofuels
- Combustion / Emissions Measurements
- Vehicle, Engine & Component Testing

Advanced Energy Storage

- Development, Testing & Analysis
- Thermal Characterization
- Life Cycle / Abuse Testing & Modeling
- Electrode Material Development

Regulatory Support

- EPA Greenhouse Gas Rulemaking
- Data & Policy Analysis
- Technical Integration
- Fleet Assistance



Vehicle Thermal Management

- Integrated Thermal Management
- Climate Control/Idle Reduction
- Advanced HVAC

Infrastructure

- Vehicle-to-Grid Integration
- Renewables
- Charging Equipment & Controls
- Fueling Stations & Equipment
- Roadway Electrification

Vehicle Fleet Test & Evaluation

- Advanced In-Field Data Collection
- Medium / Heavy Duty (MD/HD) Testing & Analysis
- Drive Cycle Analysis
- Big Data Collection, Storage & Analysis
- Vehicle Modeling & Simulation
- Optimization Tools & Analysis
- MD/HD Dynamometer Testing

Advanced Power Electronics & Electric Motors

- Thermal Management
- Thermal Stress and Reliability

Vehicle Deployment / Clean Cities

- Guidance & Information for Fleet Managers and Policy Makers
- Technical Assistance
- Online Data, Tools & Analysis

NREL Medium and Heavy-Duty Fleet Evaluations

Field Test and Evaluation provides medium-duty (MD) and heavy-duty (HD) test results, aggregated data, and detailed analysis.

- **3rd party unbiased data:** Provides data that would not normally be shared by industry in an aggregated and detailed manner
- **Over 9 million miles** of advanced technology **MD and HD truck data have been collected, documented, and analyzed** on over 240 different vehicles since 2002
- **Data, Analysis, and Reports** are shared within DOE, national laboratory partners, and industry for R&D planning and strategy development
- **Results help:**
 - Guide R&D for new technology development
 - Help define intelligent usage of newly developed technology
 - Help fleets/users understand all aspects of advanced technology

Figure 6: Average driving speed vs. acceleration speed using the 10000000 mile dataset.

Looking at the distribution of the observed data as a function of characteristic acceleration and maximum speed (Figure 6), the data points are clustered into three distinct regions. The first cluster is at low acceleration and low maximum speed. The second cluster is at high acceleration and low maximum speed. The third cluster is at high acceleration and high maximum speed.

Figure 7: Characteristic acceleration vs. acceleration speed using the 10000000 mile dataset.

To better understand the drive cycle business process at each individual location, we can compare the average 1000 mile drive cycle metrics and their associated standard deviations for all trips in a cluster. The following table is derived from Figure 7. Cluster 1 is characterized by low acceleration and low maximum speed. Cluster 2 is characterized by high acceleration and low maximum speed. Cluster 3 is characterized by high acceleration and high maximum speed.

Table 1: The results for cluster using the 10000000 mile dataset.

Cluster	Max Acc (m/s ²)	Max Speed (m/s)	Mean Acc (m/s ²)	Mean Speed (m/s)	Std Dev Acc (m/s ²)	Std Dev Speed (m/s)
Cluster 1	0.5	10	0.2	5	0.1	1
Cluster 2	1.5	10	1.0	5	0.2	1
Cluster 3	1.5	20	1.0	10	0.2	2

Fast Charge Battery Electric Transit Bus In-Use Fleet Evaluation
Preprint
Robert Prohaska, Leslie Eudy, and Kenneth Kelly
To be presented at ITEC 2016: IEEE Transportation Electrification Conference and Expo
Dearborn, Michigan
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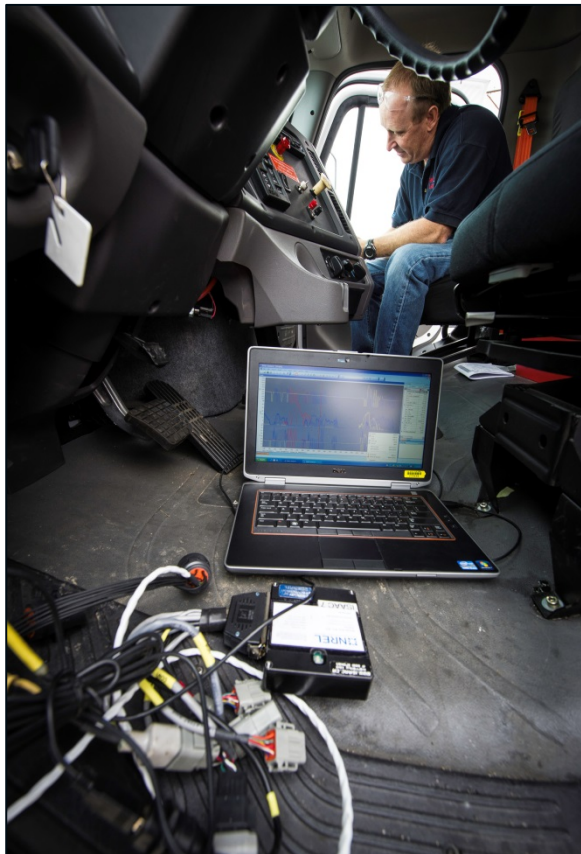
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Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC
This report is available at no cost from the National Renewable Energy
Laboratory (NREL) at www.nrel.gov/publications.
Conference Paper
NREL CP-640-00000
May 2016



Field Data Collection

- In support of multiple projects, NREL has collected in-use field data from 30 separate vehicles operating in the ports of Los Angeles and Long Beach (POLA/POLB).

NREL 22751

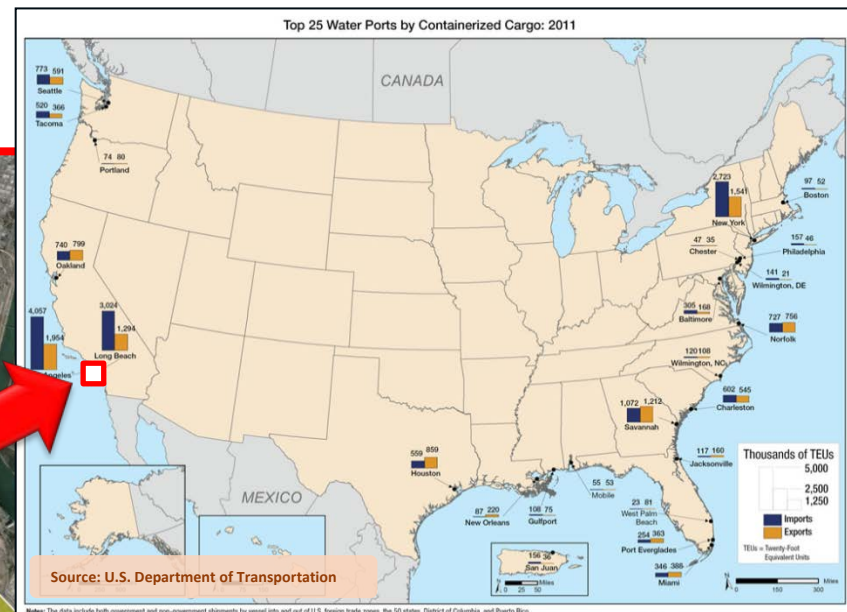


Port Drayage Field Data

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

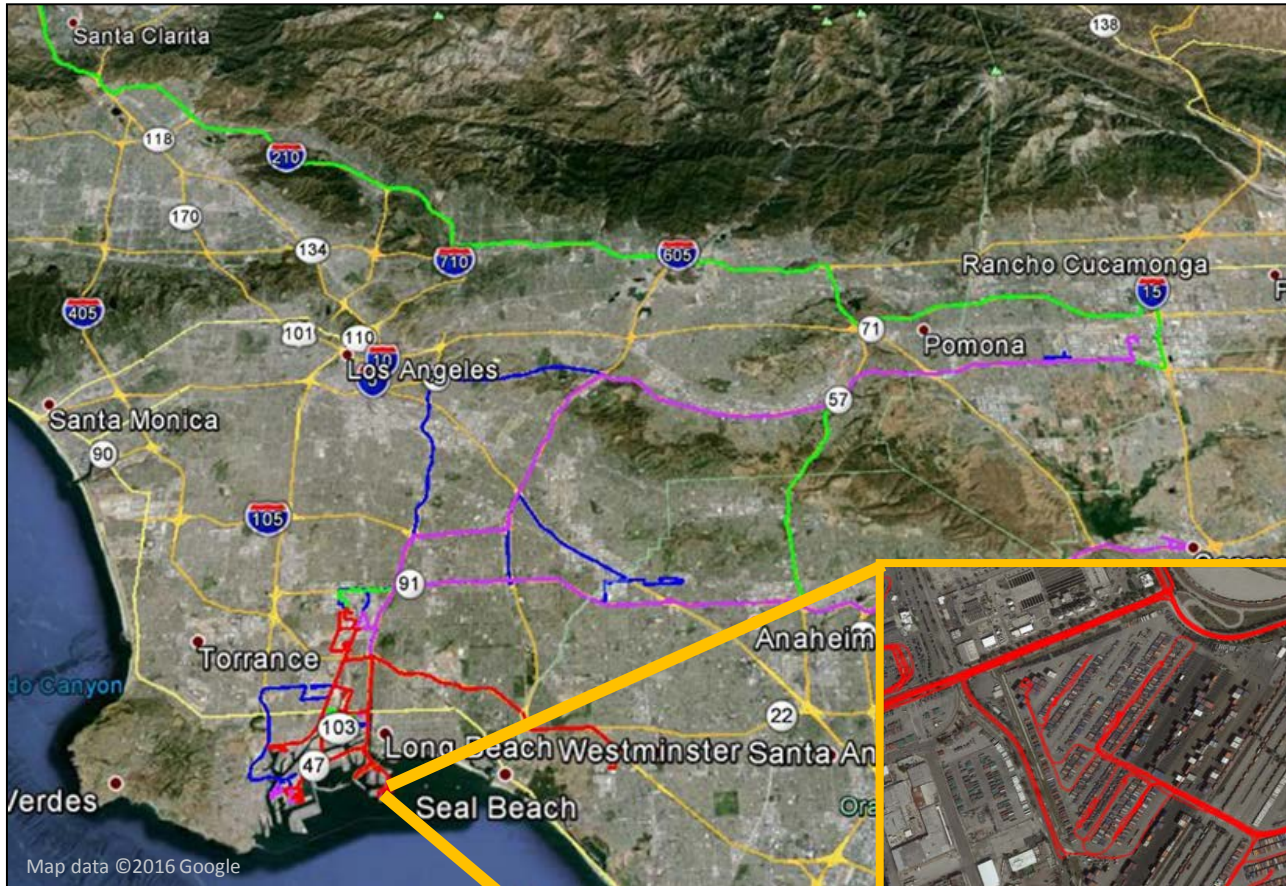
Port of Los Angeles / Port of Long Beach

- Collectively the two ports form the largest and busiest container port in the United States and the fifth busiest in the world



- 15,000 acres of sea and land under port authority

Sample Routes



NREL 35578

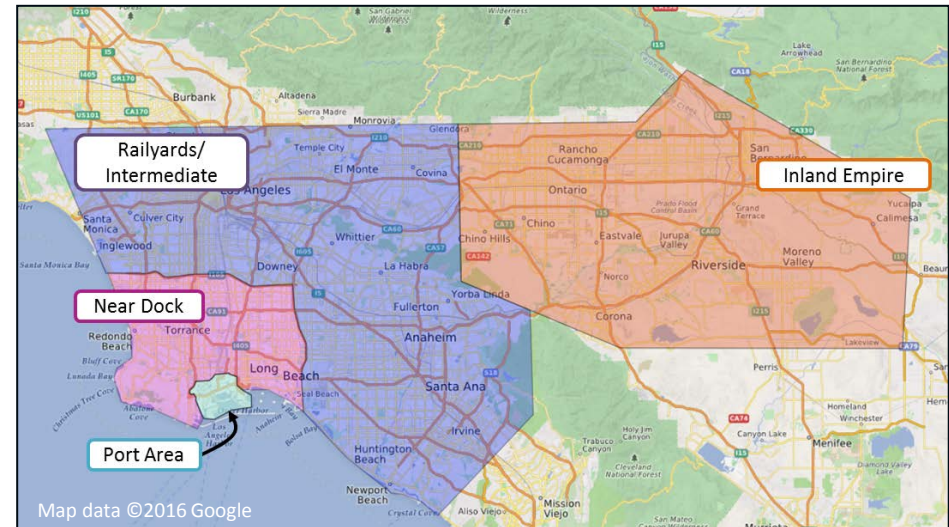


- Routes consist of highway, urban and on-port driving

Geospatial Analysis

- Trip-level geospatial origin and destination analysis demonstrated most activity in one of six combinations:

- 1) From: Port Area | To: Port Area
- 2) From: Near Dock | To: Near Dock
- 3) From: Port Area | To: Near Dock
- 4) From: Near Dock | To: Port Area
- 5) From: Near Dock | To: Inland Empire
- 6) From: Inland Empire | To: Near Dock



- Trip defined as a key-cycle (on/off) event

Geospatial Analysis

- Six of 25 trip combinations include:
 - 74% of the total mileage
 - 75% of the total fuel consumed
 - 83% of the total operating time

		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%	

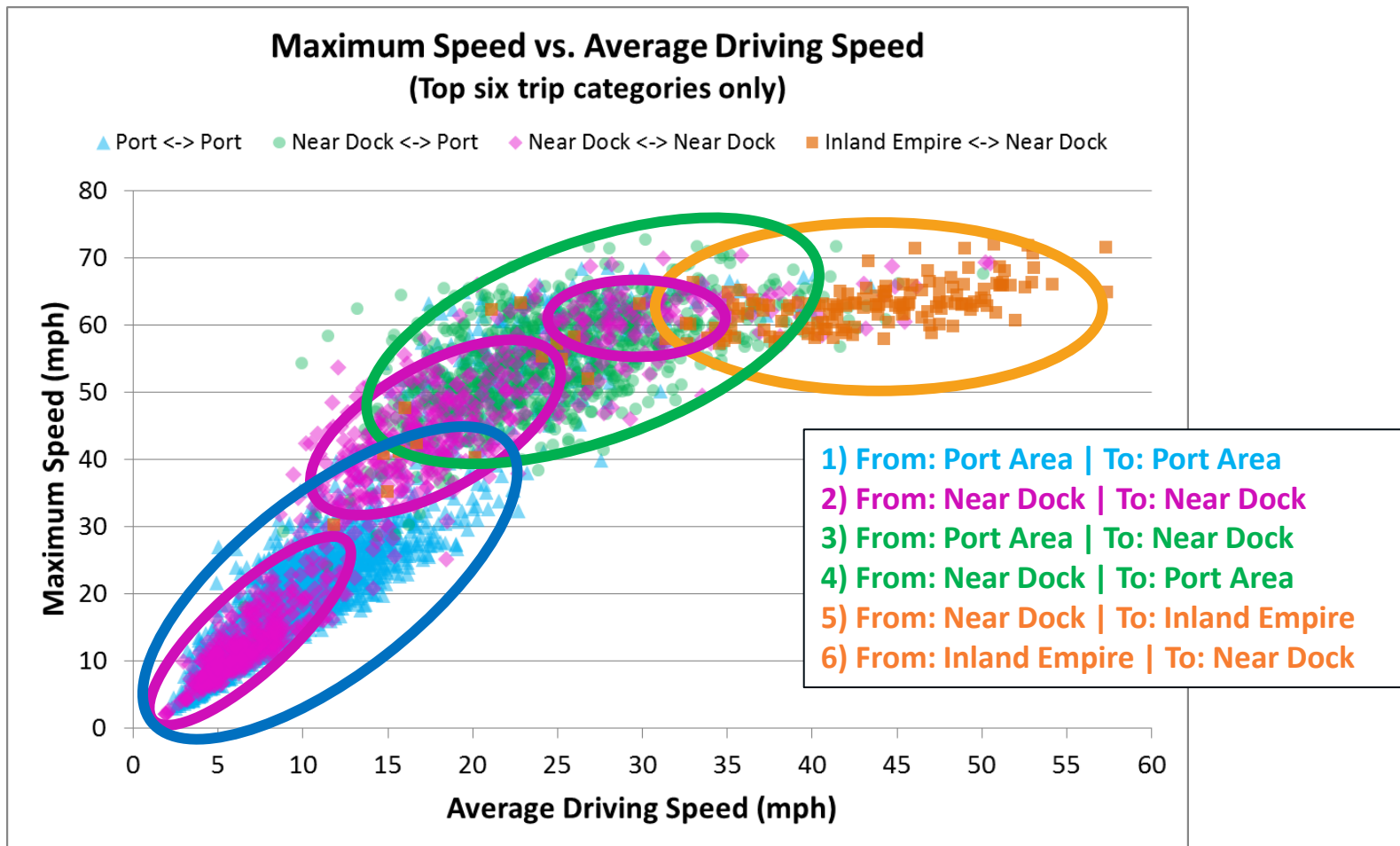
		Fuel Consumption				
To \ From	Port Area	Near Dock	Rail Yard/Inter.	Inland Empire	Other	
Port Area	18.1%	14.1%	2.1%	1.9%	0.0%	
Near Dock	11.3%	10.5%	4.8%	12.8%	2.0%	
Rail Yard/Inter.	2.6%	2.8%	1.6%	0.7%	0.0%	
Inland Empire	2.8%	8.3%	0.6%	1.7%	0.0%	
Other	0.4%	0.7%	0.0%	0.1%	0.2%	

		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%	

- 1) From: Port Area | To: Port Area
- 2) From: Near Dock | To: Near Dock
- 3) From: Port Area | To: Near Dock
- 4) From: Near Dock | To: Port Area
- 5) From: Near Dock | To: Inland Empire
- 6) From: Inland Empire | To: Near Dock

Geospatial Analysis

- While the vehicles may start and stop their trips in the same region, the trip activity could vary widely

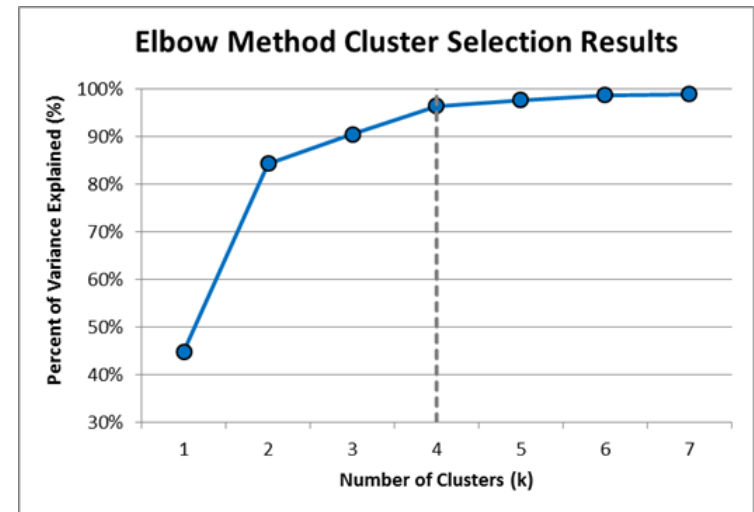


Clustering Analysis

- **Step 1:** Trip-level metrics selected to define kinematic driving behavior
- **Step 2:** Metrics scaled using the z-score scaling method
- **Step 3:** Identify number of clusters using both mean shift and elbow method
- **Step 4:** Use k-medoid clustering algorithm

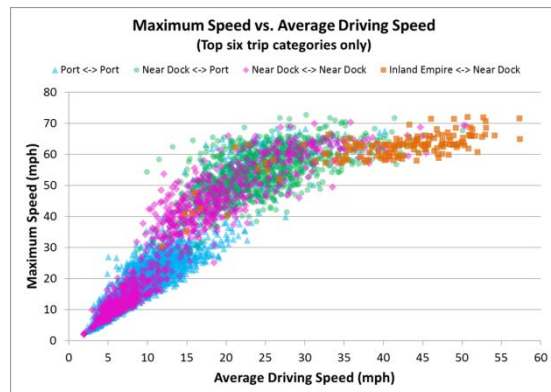
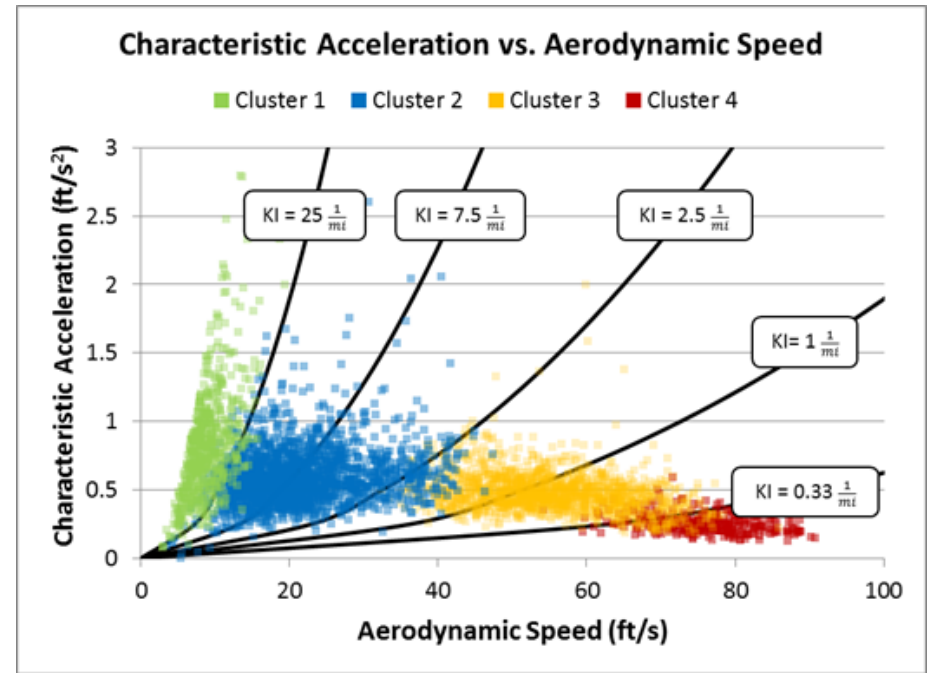
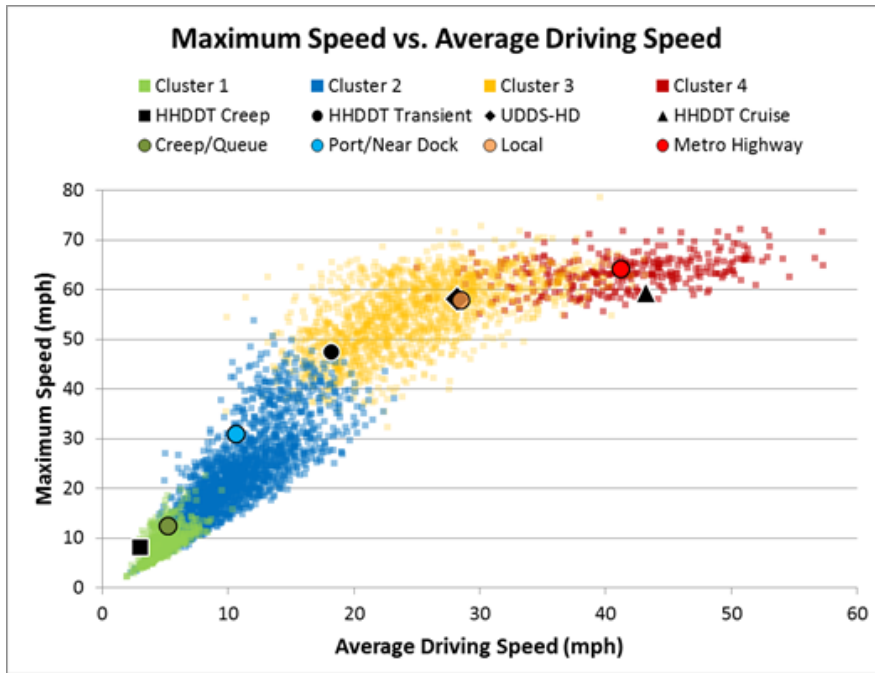
- Aerodynamic speed
- Average driving speed
- Characteristic acceleration
- Kinetic intensity
- Maximum speed
- Stops/mile
- Total average speed
- Total distance
- Total stops

$$F(x) = \text{minimize} \sum_{i=1}^n \sum_{j=1}^n d(i,j)z_{ij}$$



Clustering Analysis

- Trip level k-medoid clustering analysis results

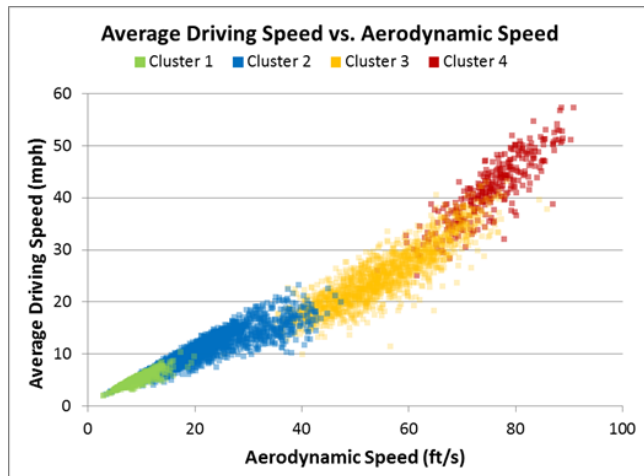


Previously shown geospatial trip classification for comparison

HHDDT: Heavy Heavy-Duty Diesel Truck
UHDS-HD: Urban Dynamometer Driving Schedule-Heavy Duty

Clustering Results – Statistics

- Trip-level statistics by cluster with standard deviation



Cluster	Cluster 1	σ	Cluster 2	σ	Cluster 3	σ	Cluster 4	σ
NREL Custom Cycle	Creep/Queue		Port/Near Dock		Local		Metro Highway	
Number of Trips in Cluster	625	N/A	1874	N/A	1551	N/A	314	N/A
Average Trip Length (mi)	0.12	0.13	1.06	0.92	11.05	6.43	54.93	25.39
Average Driving Speed (mph)	4.90	1.20	10.76	3.38	24.81	5.74	41.76	6.08
Average Total Speed (mph)	0.94	0.70	4.33	2.87	14.74	6.61	32.53	8.34
Average Total Stops	2.83	3.17	4.54	4.15	13.73	9.53	14.97	11.38
Average Stops per Mile	20.15	15.57	5.53	3.97	1.41	0.92	0.28	0.18
Average Maximum Speed (mph)	8.81	3.03	22.72	8.64	54.89	7.21	63.44	3.40
Average Kinetic Intensity (1/mi)	55.10	22.17	8.84	6.45	0.94	0.50	0.24	0.09
Average Aerodynamic Speed (ft/s)	9.10	2.52	21.82	7.60	54.91	9.24	75.63	6.53
Average Characteristic Acceleration (ft/s ²)	0.82	0.43	0.60	0.27	0.48	0.14	0.25	0.07
Percent of Zero Speed Time (%)	81%	13%	61%	21%	42%	18%	22%	14%

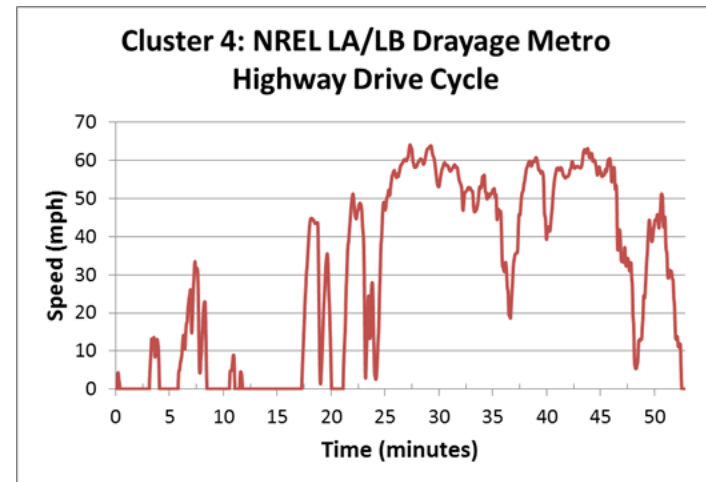
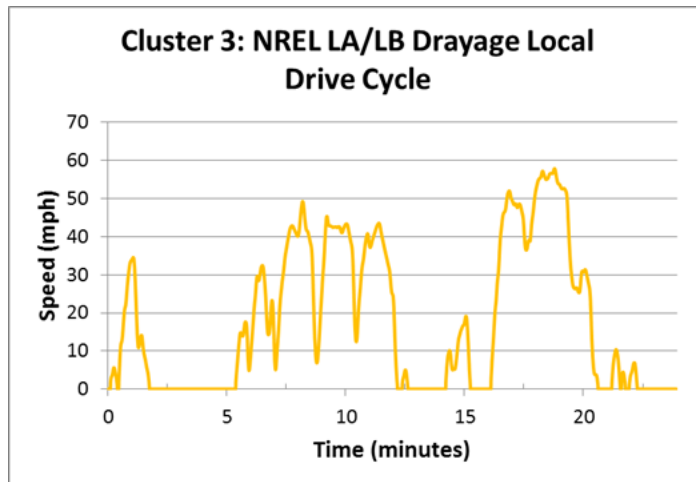
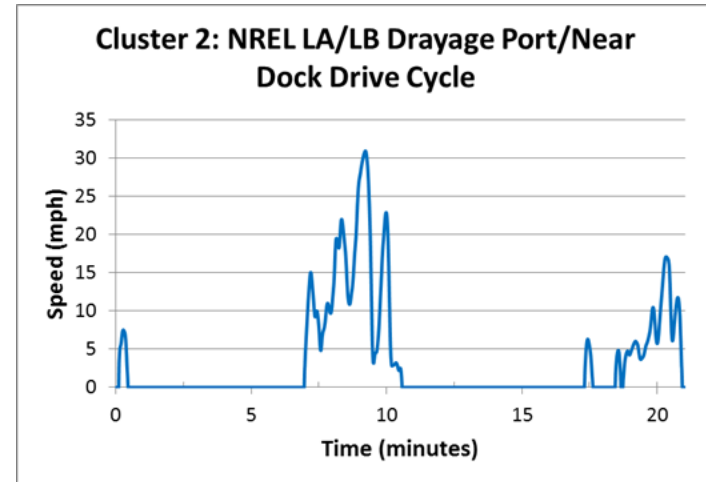
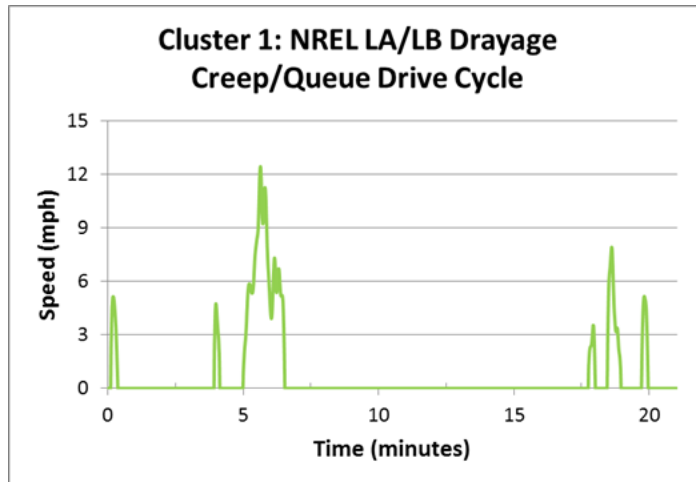
Clustering Results – Statistics

- Distribution of distance, trips, operating time, and fuel consumption by cluster
- Clusters named generically based on composition of trip behavior and location.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
	Creep/ Queue	Port/ Near Dock	Local	Metro Highway
Distance	0.2%	5.6%	48.8%	45.3%
Number of Trips	14.4%	43.2%	35.7%	6.7%
Operating Time	4.2%	23.0%	53.3%	19.5%
Fuel	1.0%	10.4%	49.5%	39.2%

Custom Drive Cycles by Cluster

- Using NREL's *DRIVE* tool, statistically representative drive cycles were created for each cluster

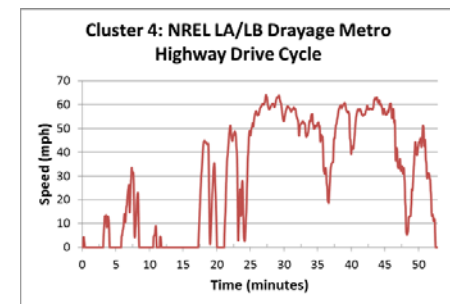
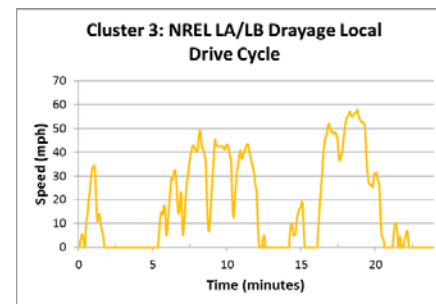
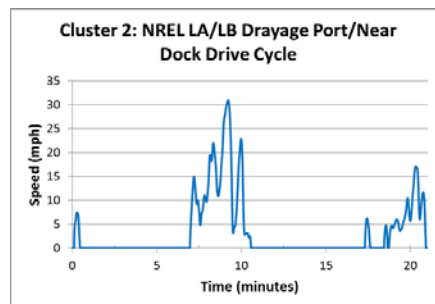
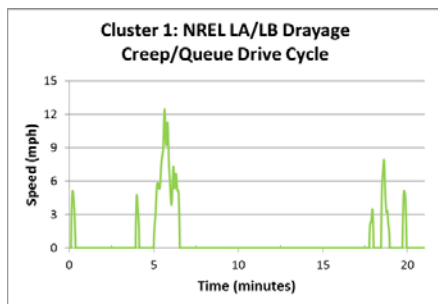


DRIVE: Drive-Cycle Rapid Investigation, Visualization, and Evaluation (<http://www.nrel.gov/transportation/drive.html>)

Custom Drive Cycles by Cluster

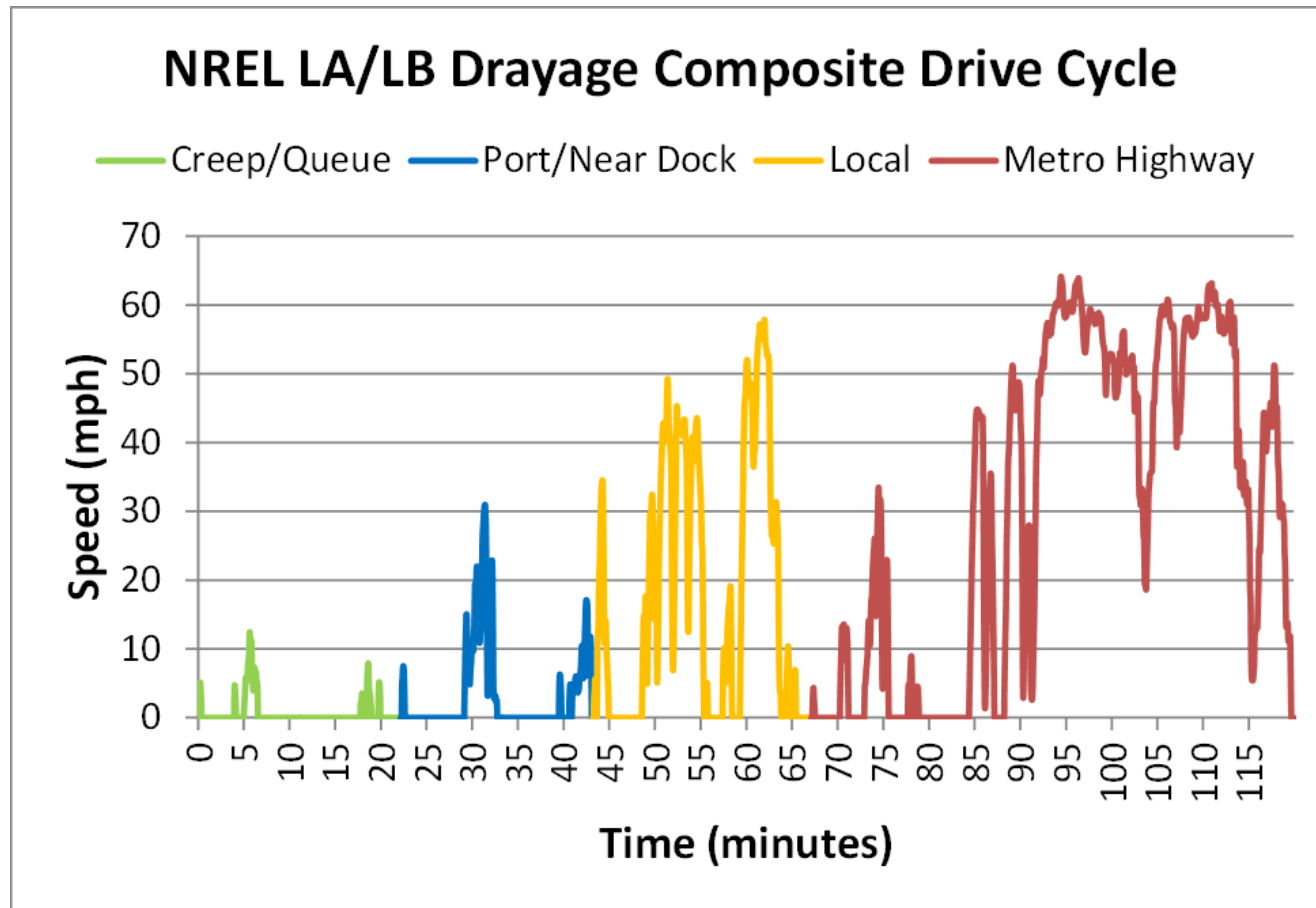
- Drive cycle metrics from custom representative cycles

Cluster	Cluster 1	Cluster 2	Cluster 3	Cluster 4
NREL Custom Cycle	Creep/Queue	Port/Near Dock	Local	Metro Highway
Drive Cycle Length (mi)	0.26	1.17	7.12	26.66
Drive Cycle Duration (minutes)	22.17	21.02	23.93	52.82
Average Driving Speed (mph)	5.20	10.61	28.53	41.23
Average Total Speed (mph)	0.70	3.34	17.86	30.29
Total Stops	6	5	9	7
Stops per Mile	23.33	4.27	1.26	0.26
Maximum Speed (mph)	12.46	30.98	57.90	64.17
Average Kinetic Intensity (1/mi)	15.89	3.79	0.69	0.24
Average Aerodynamic Speed (ft/s)	10.40	25.88	59.30	75.07
Average Characteristic Acceleration (ft/s ²)	0.33	0.48	0.46	0.25



NREL POLA/POLB Composite Drive Cycle

- Cycles can be run independently or combined into a single composite cycle



Future Work

- Apply same methodology to other vocations to identify & characterize unique operating modes

- Package delivery trucks
- School buses
- Transit buses
- Utility aerial trucks
- Refuse trucks




- Create representative drive cycles for each unique mode identified and make publically available

Applying Drive Cycle Data – NREL DriveCAT

Objectives

- Provide a common, publicly available, easy-to-use site for standard and custom drive cycles for MD / HD vehicles
- Capture, quantify and compare drive cycle variation across the spectrum of MD / HD vocations
- Allow users to download raw time series data of drive cycles for their own use

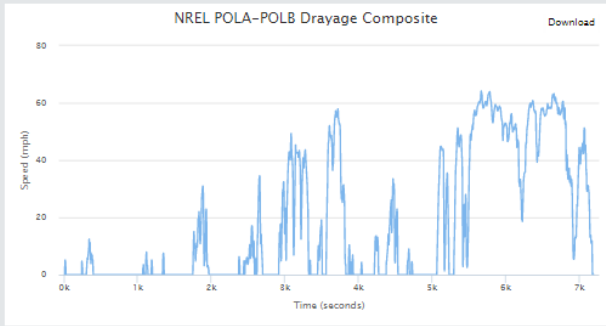
Drive Cycle Analysis Tool – DriveCAT



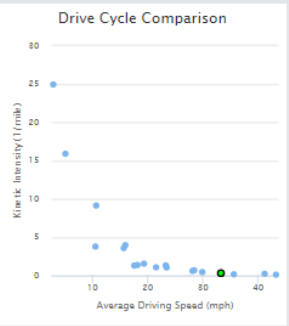
Use the Drive Cycle Analysis Tool (DriveCAT) to find drive cycle data for modeling, simulating, and testing vehicle systems and components, or to understand the real-world benefits of drive cycles for specific vehicle applications.

This tool was created by NREL's fleet test and evaluation team, which conducts in-service performance evaluations of advanced medium- and heavy-duty fleet vehicles. Evaluation results help vehicle manufacturers fine-tune their designs and help fleet managers select fuel-efficient, low-emission vehicles that meet their needs. Learn more about [NREL's fleet test and evaluation research](#).

Contact Us
 Let us know if you have any questions about the data, need assistance, or would like to contribute test cycles. We also welcome your feedback on the tool.
[CONTACT US](#)



NREL POLA-POLB Drayage Composite



Drive Cycle Comparison

Select a Drive Cycle

DOWNLOAD CSV

Cycle	Time (minutes)	Distance (mi)	Max Speed (mph)	Avg Speed (mph)	Avg Driving Speed (mph)	PKE (ft/sec ²)	KI (1/mi)	Stops (#)
CARB HHDDT Composite	60.08	26.05	59.30	26.01	35.59	0.35	0.17	13
CARB HHDDT Creep Segment	4.23	0.12	8.20	1.76	3.00	0.43	24.93	3
CARB HHDDT Cruise Segment	34.73	23.07	59.30	39.86	43.22	0.27	0.12	6
CARB HHDDT Transient Segment	11.13	2.85	47.50	15.36	18.20	0.98	1.38	4
Central Business District - CBD	9.35	2.05	20.00	13.13	15.94	1.12	3.97	14
Manhattan Bus Cycle 10Hz	18.15	2.07	25.40	6.83	10.67	0.19	9.14	20
NREL Baltimore Parcel Delivery	64.23	20.46	61.70	19.11	23.37	1.53	1.33	41
NREL Miami-Dade Refuse	15.02	1.94	52.77	7.74	17.57	1.39	1.31	20
NREL Navistar eStar ARRA	61.62	6.53	48.73	6.36	19.42	1.43	1.56	32
NREL Neighborhood Refuse Truck	30.55	5.69	60.00	11.17	21.52	1.36	1.08	60
NREL PG&E Utility Truck	34.30	11.16	58.50	19.53	29.92	0.79	0.46	20
NREL POLA-POLB Drayage Composite	119.95	35.21	64.17	17.61	33.34	0.60	0.32	27

Drive-Cycle Description

A four-mode chassis dynamometer test cycle developed by NREL from drayage driving data in and around the Ports of Los Angeles and Long Beach (POLA/POLB).

Related NREL Resources

- [Heavy-Duty Vehicle Port Drayage Drive Cycle Characterization and Development](#)

www.nrel.gov/transportation/drive-cycle-tool

NREL Medium- and Heavy-Duty Fleet Testing and Technology Evaluations

Supported by:

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Vehicle Technologies Office**

Vehicle Systems Program

– Lee Slezak and David Anderson



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