NREL
NATIONAL RENEWABLE ENERGY LABORATORY





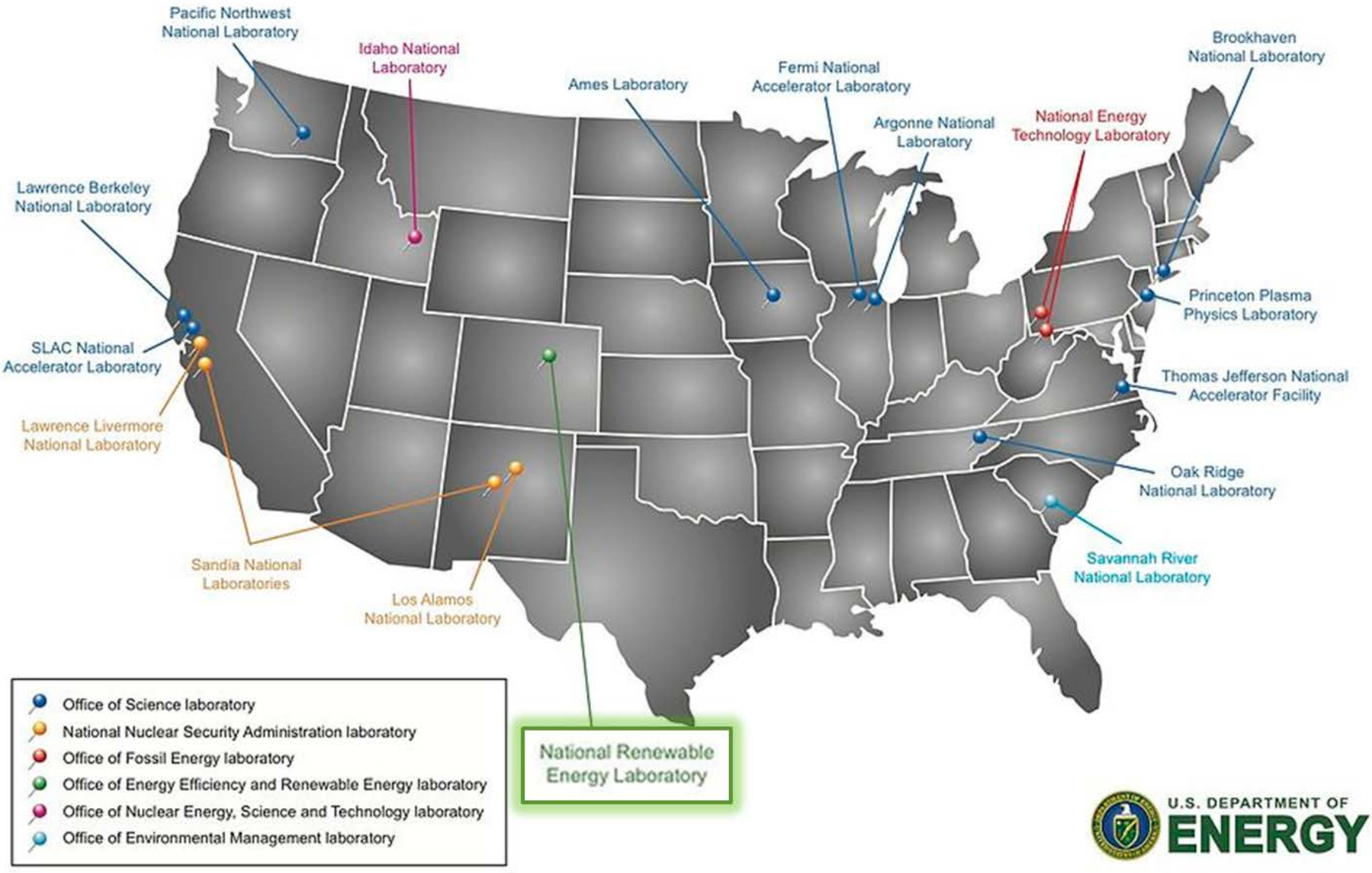
Heavy-Duty Vehicle Port Drayage Drive Cycle Characterization and Development

NREL/PR-5400-67291

Robert Prohaska, Arnaud Konan, Kenneth Kelly & Michael Lammert

SAE 2016 Commercial Vehicle 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

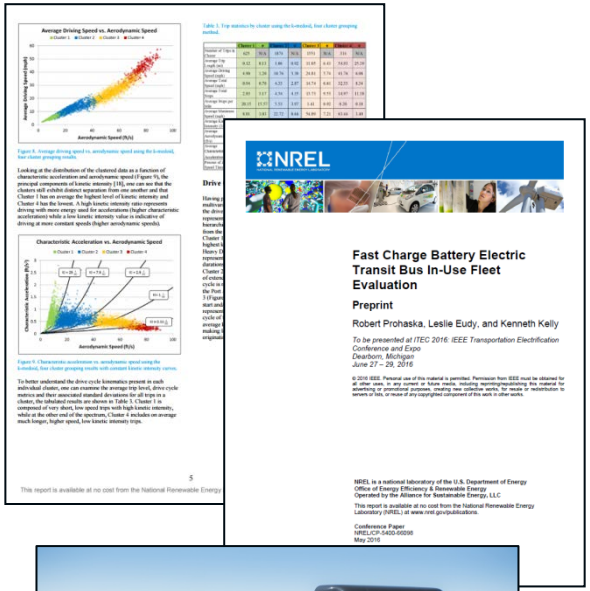
Field Test and Evaluation provides medium-duty (MD) and heavy-duty (HD) test results, aggregated data, and detailed analysis.

- **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

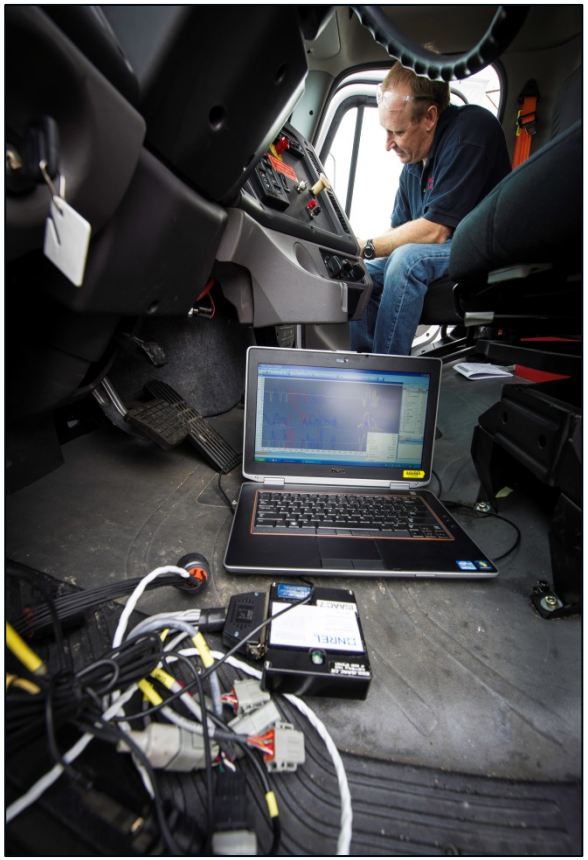
- **Results help:**
  - Guide R&D for new technology development
  - Help define intelligent usage of newly developed technology
  - Help fleets/users understand all aspects of advanced technology



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).

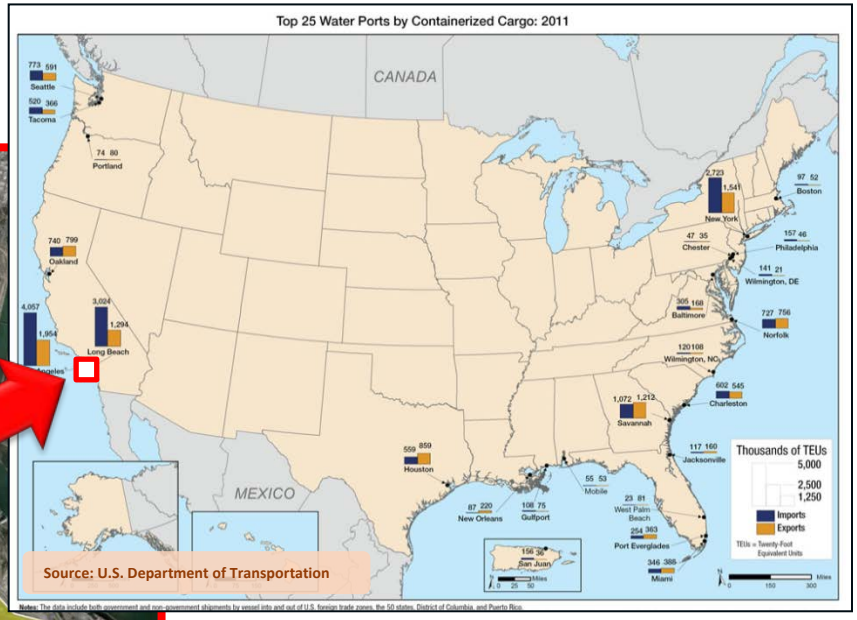
NREL 22751



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

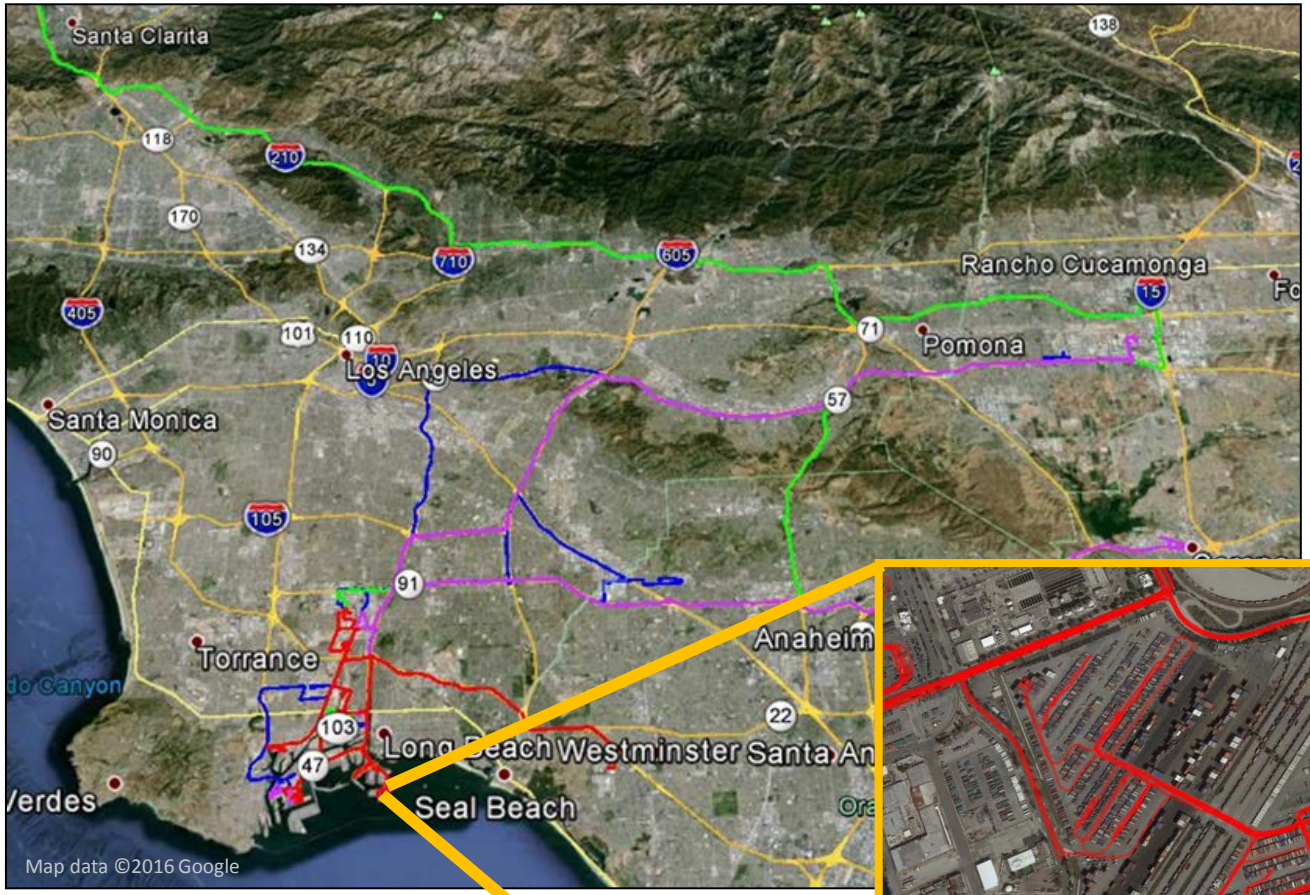
Port of Los Angeles / Port of Long Beach

- 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



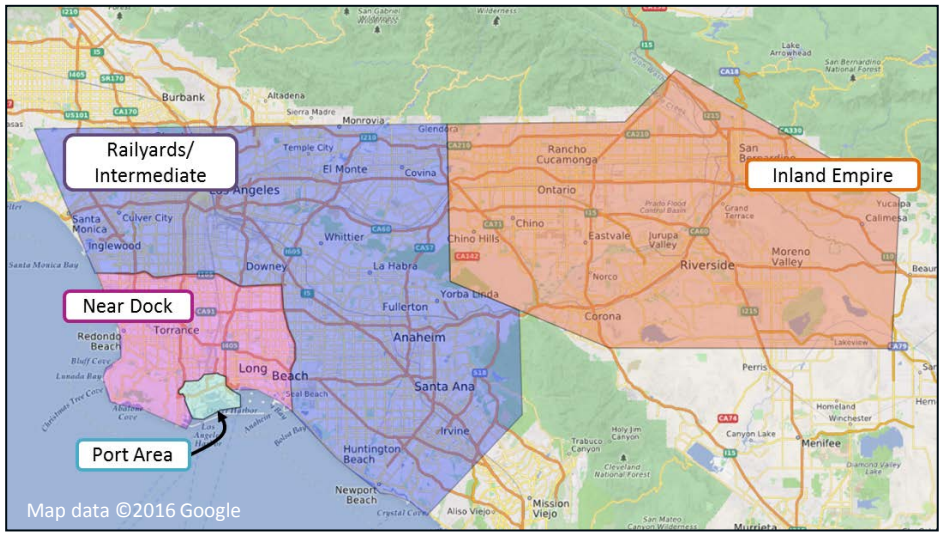
NREL 35578

- 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

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

Mileage

From \ To	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

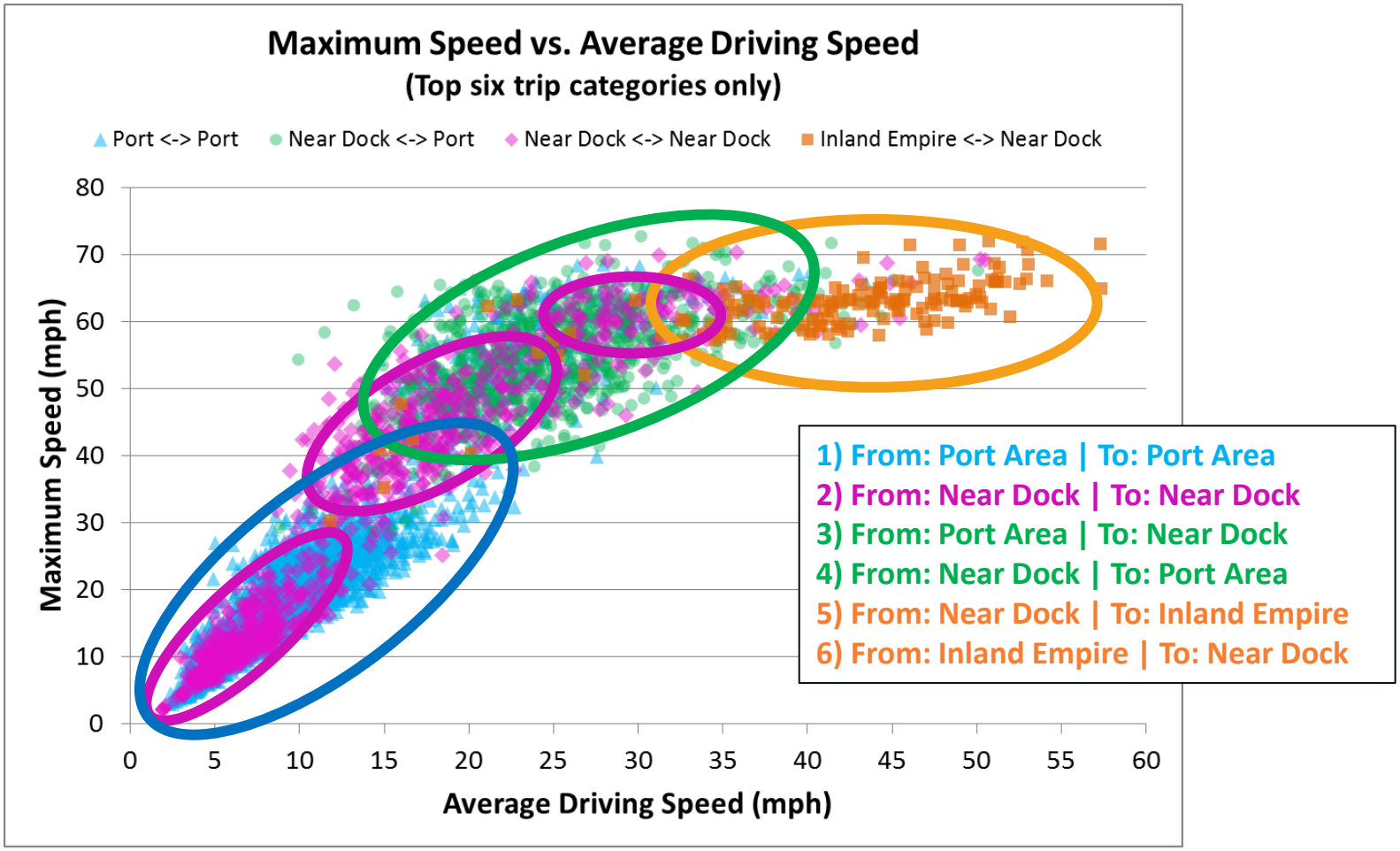
From \ To	Port Area	Near Dock	Rail Yard/Inter.	Inland Empire	Other
Port Area	**18.1%**	**14.1%**	2.1%	1.9%	0.0%
Near Dock	**11.3%**	**10.5%**	4.8%	**12.8%**	2.0%
Rail Yard/Inter.	2.6%	2.8%	1.6%	0.7%	0.0%
Inland Empire	2.8%	**8.3%**	0.6%	1.7%	0.0%
Other	0.4%	0.7%	0.0%	0.1%	0.2%

Operating Time

From \ To	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%

Geospatial Analysis

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

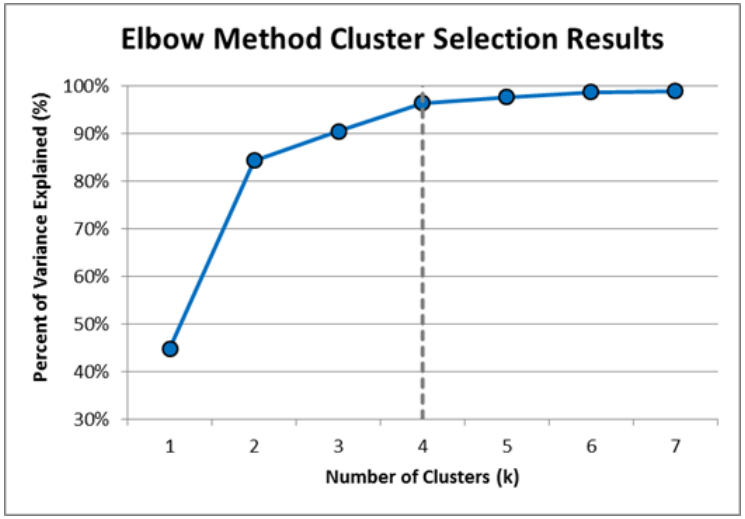


Clustering Analysis

- **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

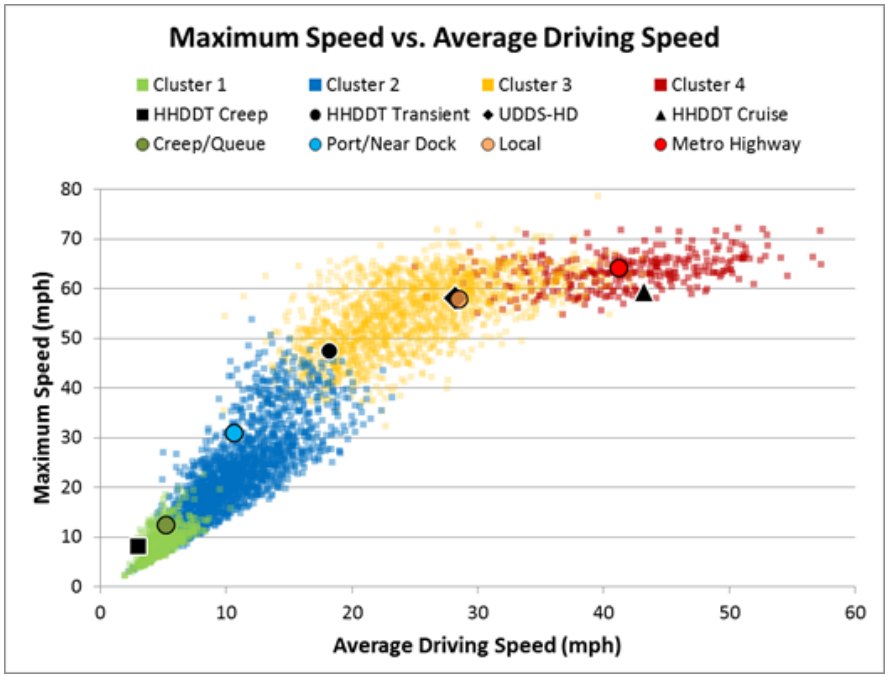
$$F\ (x) = minimize \sum_{i=1}^{n}\sum_{j=1}^{n} d(i,j)z_{ij}$$

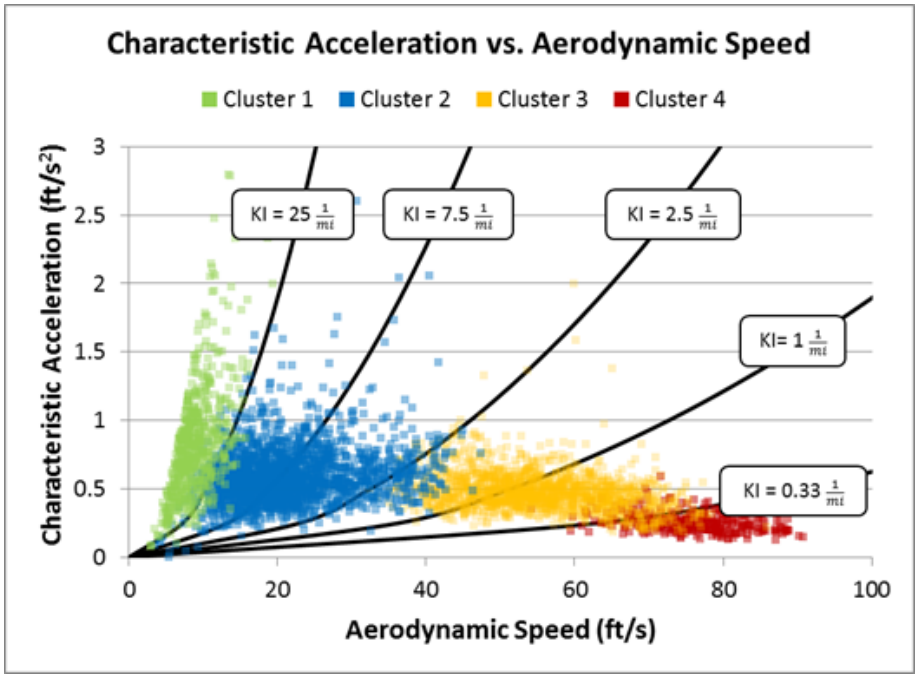
- Aerodynamic speed
- Average driving speed
- Characteristic acceleration
- Kinetic intensity
- Maximum speed
- Stops/mile
- Total average speed
- Total distance
- Total stops

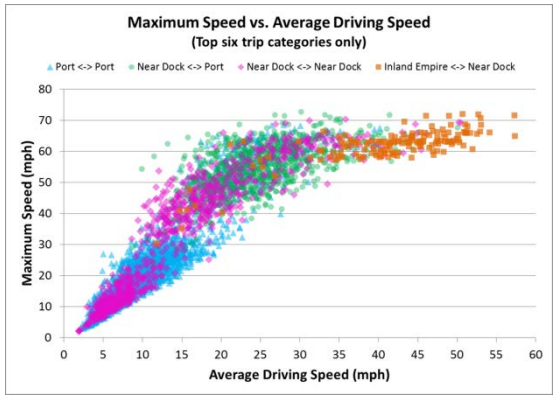


Clustering Analysis

- Trip level k-medoid clustering analysis results





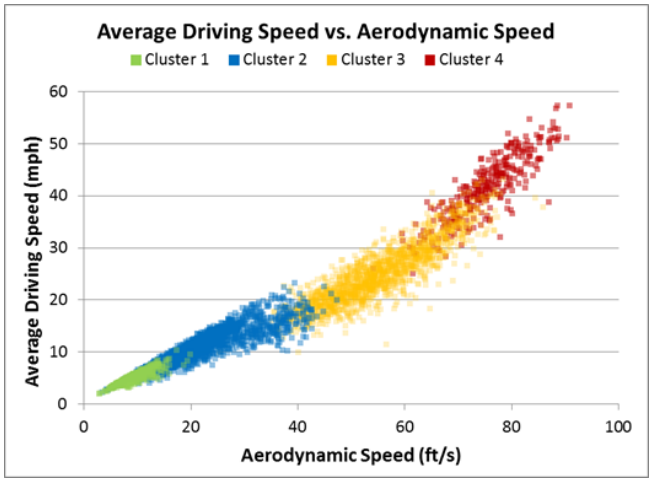


Previously shown geospatial trip classification for comparison

HHDDT: Heavy Heavy-Duty Diesel Truck
UDDS-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%

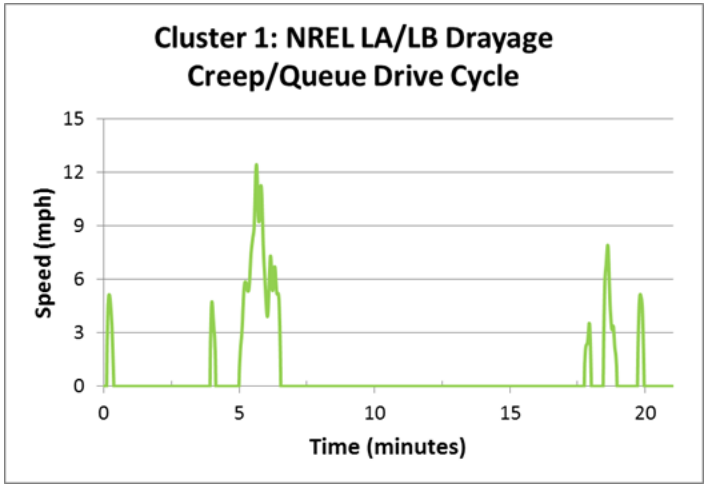
Clustering Results – Statistics

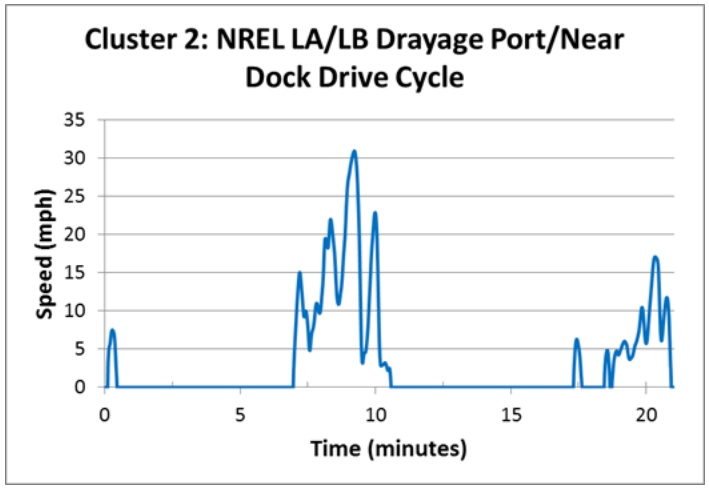
- Distribution of distance, trips, operating time, and fuel consumption by cluster
- Clusters named generically based on composition of trip behavior and location.

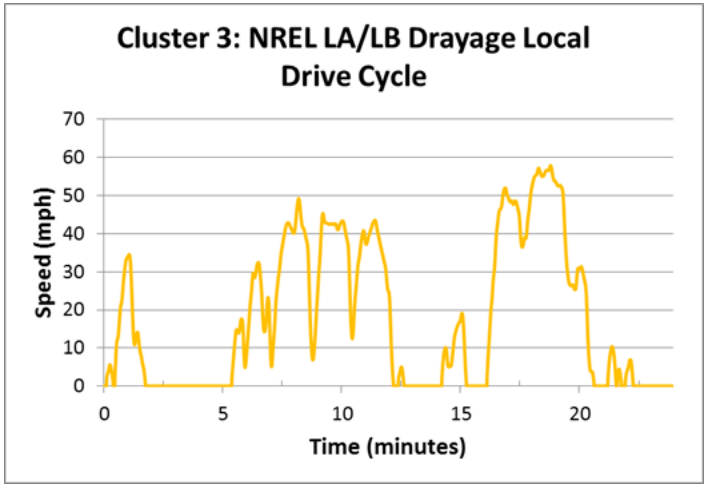
	Cluster 1	Cluster 2	Cluster 3	Cluster 4
	Creep/ Queue	Port/ Near Dock	Local	Metro Highway
Distance	0.2%	5.6%	48.8%	45.3%
Number of Trips	14.4%	43.2%	35.7%	6.7%
Operating Time	4.2%	23.0%	53.3%	19.5%
Fuel	1.0%	10.4%	49.5%	39.2%

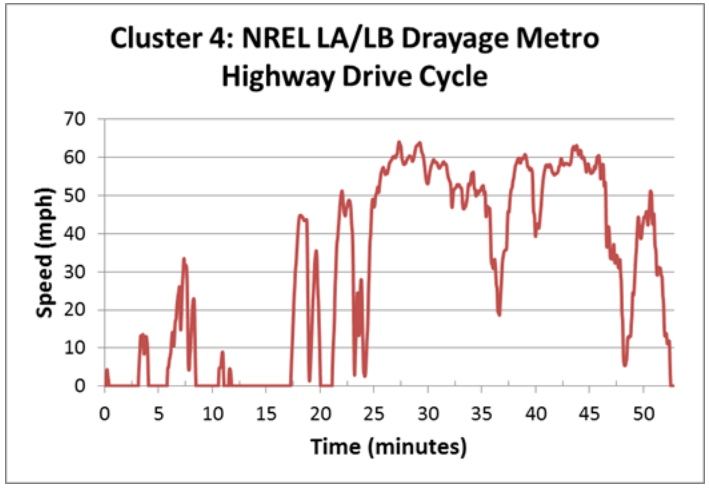
Custom Drive Cycles by Cluster

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







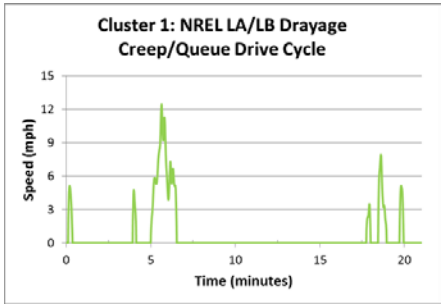


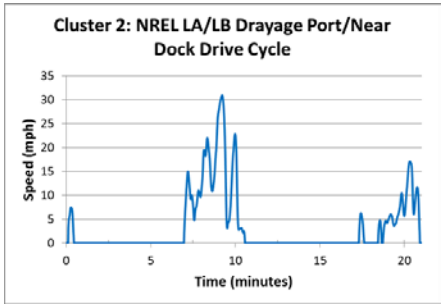
DRIVE: Drive-Cycle Rapid Investigation, Visualization, and Evaluation (http://www.nrel.gov/transportation/drive.html)

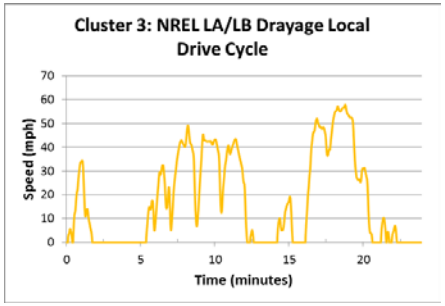
Custom Drive Cycles by Cluster

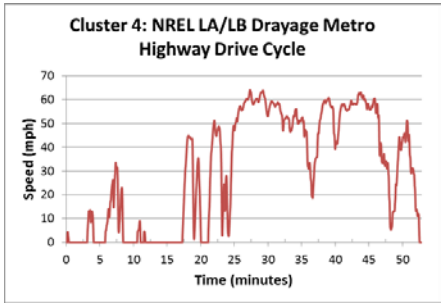
- Drive cycle metrics from custom representative cycles

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



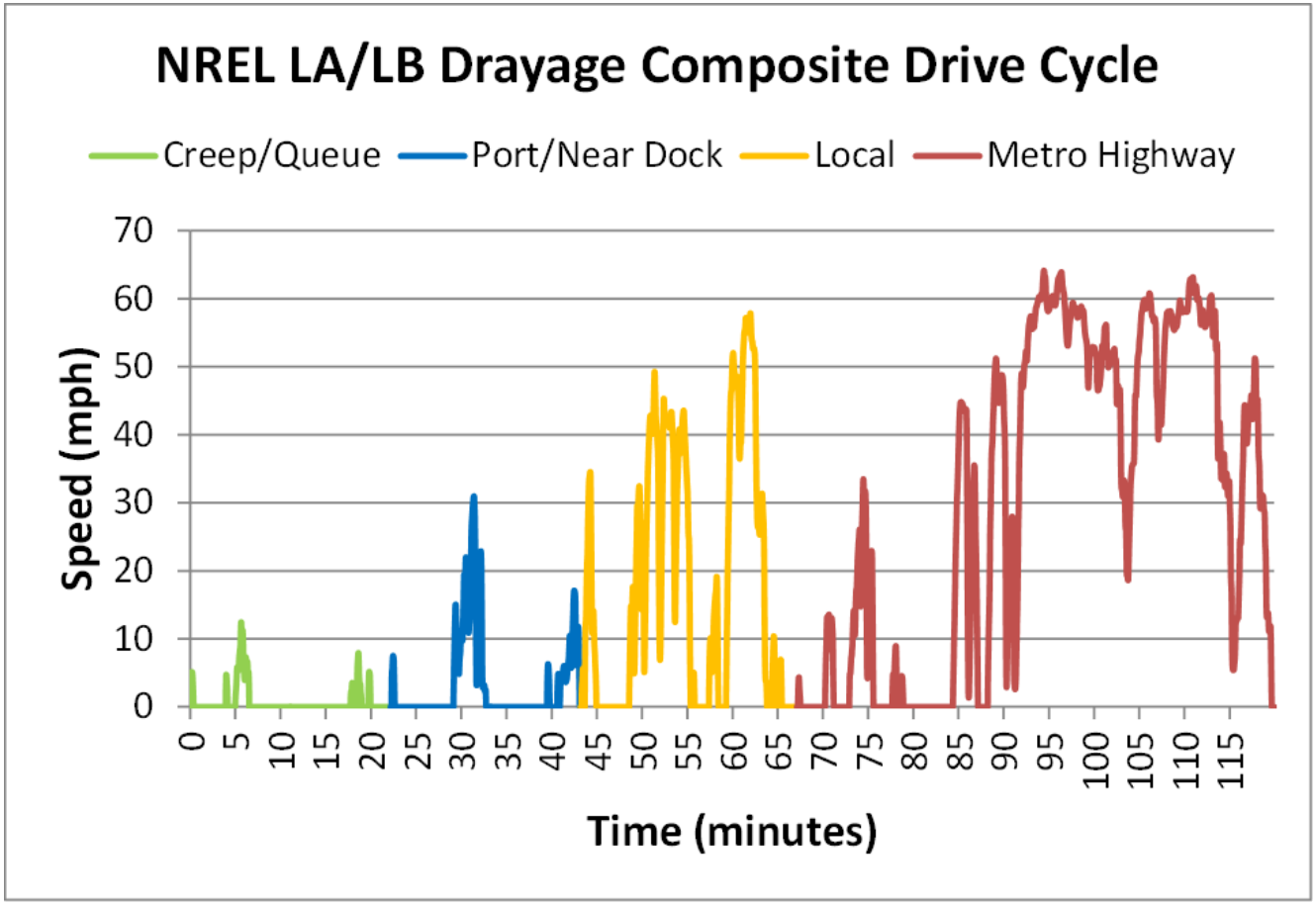






NREL POLA/POLB Composite Drive Cycle

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



Future Work

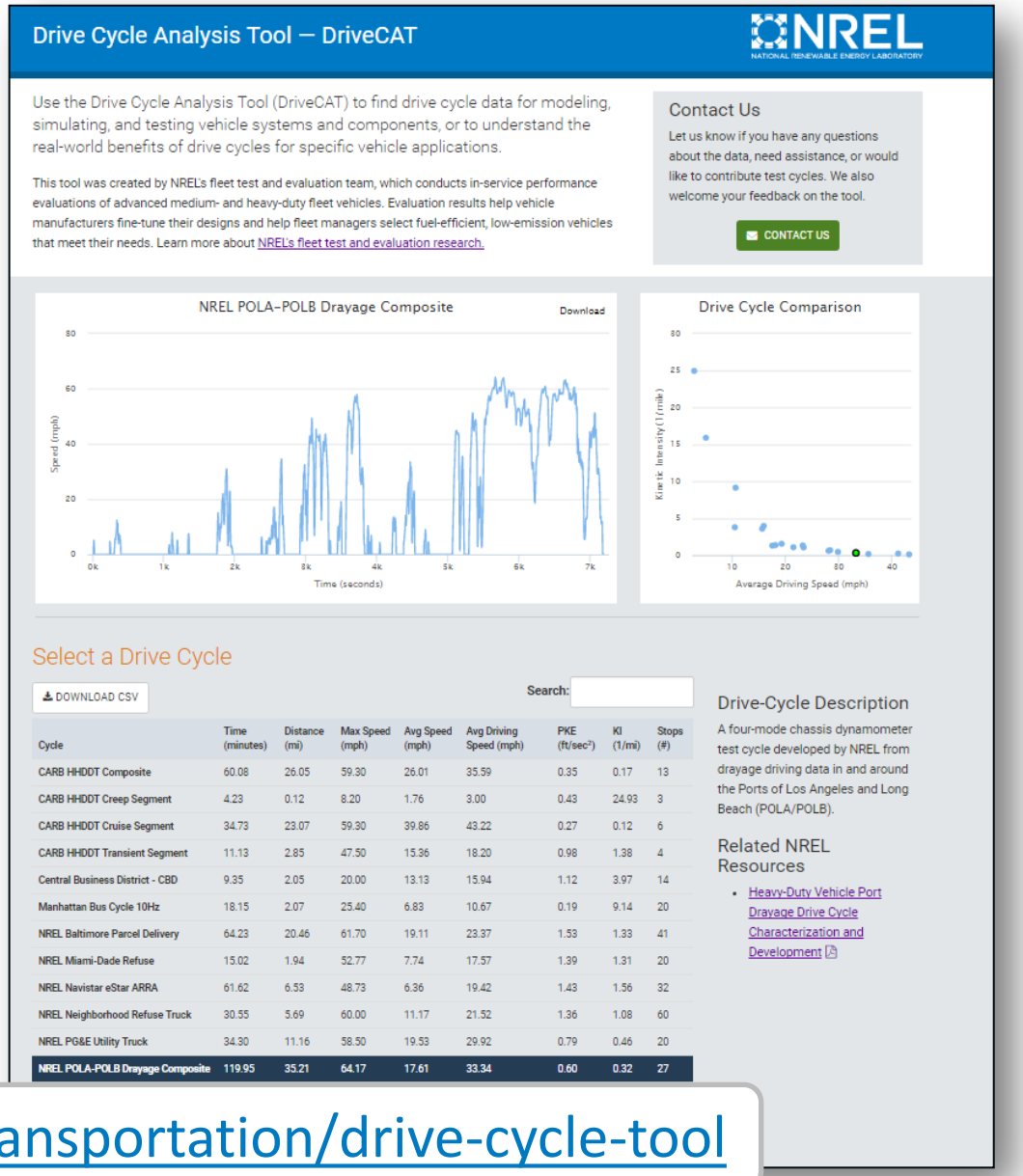
- Apply same methodology to other vocations to identify & characterize unique operating modes
  - Package delivery trucks
  - School buses
  - Transit buses
  - Utility aerial trucks
  - Refuse trucks

- 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



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

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

Supported by:
U.S. Department of Energy
Vehicle Technologies Office
Vehicle Systems Program
– Lee Slezak and David Anderson

Questions / Comments / Collaboration:

Robert Prohaska
Robert.Prohaska@NREL.gov

Kenneth Kelly (Task Leader)
Kenneth.Kelly@NREL.gov

www.nrel.gov

NREL
NATIONAL RENEWABLE ENERGY LABORATORY