Heavy-Duty Vehicle Port Drayage Drive Cycle Characterization and Development

NREL/PR-5400-67291

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US Department of Energy National Labs

[Map of the United States with various national laboratories marked, including Pacific Northwest National Laboratory, Idaho National Laboratory, Lawrence Berkeley National Laboratory, SLAC National Accelerator Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratories, Los Alamos National Laboratory, Argonne National Laboratory, Fermi National Accelerator Laboratory, Ames Laboratory, Brookhaven National Laboratory, Princeton Plasma Physics Laboratory, Thomas Jefferson National Accelerator Facility, Oak Ridge National Laboratory, Savannah River National Laboratory, and National Renewable Energy Laboratory.]
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 Deployment / Clean Cities**
- Guidance & Information for Fleet Managers and Policy Makers
- Technical Assistance
- Online Data, Tools & Analysis

**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
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
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).

### Port Drayage Field Data

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mileage</td>
<td>36,444 Miles</td>
</tr>
<tr>
<td>Total hours of operation</td>
<td>2,809 Hours</td>
</tr>
<tr>
<td>Driving days</td>
<td>557 Days</td>
</tr>
<tr>
<td>Operating companies</td>
<td>3 Companies</td>
</tr>
<tr>
<td>Unique vehicles</td>
<td>30 Vehicles</td>
</tr>
<tr>
<td>Vehicle manufacturers</td>
<td>Navistar, Volvo, Mack, Freightliner, Peterbilt &amp; Sterling</td>
</tr>
</tbody>
</table>
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

- Routes consist of highway, urban and on-port driving
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
Six of 25 trip combinations include:
- 74% of the total mileage
- 75% of the total fuel consumed
- 83% of the total operating time

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Mileage</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Area</td>
<td>Port Area</td>
<td>14.9%</td>
<td>13.7%</td>
<td>1.8%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Near Dock</td>
<td>Near Dock</td>
<td>12.3%</td>
<td>10.4%</td>
<td>4.6%</td>
<td>12.2%</td>
</tr>
<tr>
<td>Rail Yard/Inter.</td>
<td>Rail Yard/Inter.</td>
<td>3.3%</td>
<td>3.1%</td>
<td>1.2%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Inland Empire</td>
<td>Inland Empire</td>
<td>3.7%</td>
<td>10.2%</td>
<td>0.7%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Other</td>
<td>Other</td>
<td>0.5%</td>
<td>0.9%</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Fuel Consumption</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Area</td>
<td>Port Area</td>
<td>18.1%</td>
<td>14.1%</td>
<td>2.1%</td>
<td>1.9%</td>
</tr>
<tr>
<td>Near Dock</td>
<td>Near Dock</td>
<td>11.3%</td>
<td>10.5%</td>
<td>4.8%</td>
<td>12.8%</td>
</tr>
<tr>
<td>Rail Yard/Inter.</td>
<td>Rail Yard/Inter.</td>
<td>2.6%</td>
<td>2.8%</td>
<td>1.6%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Inland Empire</td>
<td>Inland Empire</td>
<td>2.8%</td>
<td>8.3%</td>
<td>0.6%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Other</td>
<td>Other</td>
<td>0.4%</td>
<td>0.7%</td>
<td>0.0%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Operating Time</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Area</td>
<td>Port Area</td>
<td>28.2%</td>
<td>15.0%</td>
<td>0.9%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Near Dock</td>
<td>Near Dock</td>
<td>10.6%</td>
<td>20.4%</td>
<td>2.8%</td>
<td>4.5%</td>
</tr>
<tr>
<td>Rail Yard/Inter.</td>
<td>Rail Yard/Inter.</td>
<td>1.6%</td>
<td>2.0%</td>
<td>3.2%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Inland Empire</td>
<td>Inland Empire</td>
<td>1.3%</td>
<td>4.1%</td>
<td>0.4%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Other</td>
<td>Other</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.0%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>
• While the vehicles may start and stop their trips in the same region, the trip activity could vary widely.

Geospatial Analysis

![Maximum Speed vs. Average Driving Speed](chart)

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
• **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

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

- 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

**Maximum Speed vs. Average Driving Speed**

**Characteristic Acceleration vs. Aerodynamic Speed**

*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**

<table>
<thead>
<tr>
<th>NREL Custom Cycle</th>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
<th>Cluster 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Trips in Cluster</td>
<td>625</td>
<td>N/A</td>
<td>1874</td>
<td>N/A</td>
</tr>
<tr>
<td>Average Trip Length (mi)</td>
<td>0.12</td>
<td>0.13</td>
<td>1.06</td>
<td>0.92</td>
</tr>
<tr>
<td>Average Driving Speed (mph)</td>
<td>4.90</td>
<td>1.20</td>
<td>10.76</td>
<td>3.38</td>
</tr>
<tr>
<td>Average Total Speed (mph)</td>
<td>0.94</td>
<td>0.70</td>
<td>4.33</td>
<td>2.87</td>
</tr>
<tr>
<td>Average Total Stops</td>
<td>2.83</td>
<td>3.17</td>
<td>4.54</td>
<td>4.15</td>
</tr>
<tr>
<td>Average Stops per Mile</td>
<td>20.15</td>
<td>15.57</td>
<td>5.53</td>
<td>3.97</td>
</tr>
<tr>
<td>Average Maximum Speed (mph)</td>
<td>8.81</td>
<td>3.03</td>
<td>22.72</td>
<td>8.64</td>
</tr>
<tr>
<td>Average Kinetic Intensity (1/mi)</td>
<td>55.10</td>
<td>22.17</td>
<td>8.84</td>
<td>6.45</td>
</tr>
<tr>
<td>Average Aerodynamic Speed (ft/s)</td>
<td>9.10</td>
<td>2.52</td>
<td>21.82</td>
<td>7.60</td>
</tr>
<tr>
<td>Average Characteristic Acceleration (ft/s²)</td>
<td>0.82</td>
<td>0.43</td>
<td>0.60</td>
<td>0.27</td>
</tr>
<tr>
<td>Percent of Zero Speed Time (%)</td>
<td>81%</td>
<td>13%</td>
<td>61%</td>
<td>21%</td>
</tr>
</tbody>
</table>
• Distribution of distance, trips, operating time, and fuel consumption by cluster

• Clusters named generically based on composition of trip behavior and location.

<table>
<thead>
<tr>
<th></th>
<th>Cluster 1</th>
<th>Cluster 2</th>
<th>Cluster 3</th>
<th>Cluster 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creep/Queue</td>
<td>0.2%</td>
<td>5.6%</td>
<td>48.8%</td>
<td>45.3%</td>
</tr>
<tr>
<td>Port/Near Dock</td>
<td>14.4%</td>
<td>43.2%</td>
<td>35.7%</td>
<td>6.7%</td>
</tr>
<tr>
<td>Local</td>
<td>4.2%</td>
<td>23.0%</td>
<td>53.3%</td>
<td>19.5%</td>
</tr>
<tr>
<td>Metro Highway</td>
<td>1.0%</td>
<td>10.4%</td>
<td>49.5%</td>
<td>39.2%</td>
</tr>
</tbody>
</table>

Clustering Results – Statistics
Custom Drive Cycles by Cluster

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

**Cluster 1: NREL LA/LB Drayage Creep/Queue Drive Cycle**

**Cluster 2: NREL LA/LB Drayage Port/Near Dock Drive Cycle**

**Cluster 3: NREL LA/LB Drayage Local Drive Cycle**

**Cluster 4: NREL LA/LB Drayage Metro Highway Drive Cycle**

**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

<table>
<thead>
<tr>
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<th>Cluster 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>NREL Custom Cycle</td>
<td>Creep/Queue</td>
<td>Port/Near Dock</td>
<td>Local</td>
<td>Metro Highway</td>
</tr>
<tr>
<td>Drive Cycle Length (mi)</td>
<td>0.26</td>
<td>1.17</td>
<td>7.12</td>
<td>26.66</td>
</tr>
<tr>
<td>Drive Cycle Duration (minutes)</td>
<td>22.17</td>
<td>21.02</td>
<td>23.93</td>
<td>52.82</td>
</tr>
<tr>
<td>Average Driving Speed (mph)</td>
<td>5.20</td>
<td>10.61</td>
<td>28.53</td>
<td>41.23</td>
</tr>
<tr>
<td>Average Total Speed (mph)</td>
<td>0.70</td>
<td>3.34</td>
<td>17.86</td>
<td>30.29</td>
</tr>
<tr>
<td>Total Stops</td>
<td>6</td>
<td>5</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Stops per Mile</td>
<td>23.33</td>
<td>4.27</td>
<td>1.26</td>
<td>0.26</td>
</tr>
<tr>
<td>Maximum Speed (mph)</td>
<td>12.46</td>
<td>30.98</td>
<td>57.90</td>
<td>64.17</td>
</tr>
<tr>
<td>Average Kinetic Intensity (1/mi)</td>
<td>15.89</td>
<td>3.79</td>
<td>0.69</td>
<td>0.24</td>
</tr>
<tr>
<td>Average Aerodynamic Speed (ft/s)</td>
<td>10.40</td>
<td>25.88</td>
<td>59.30</td>
<td>75.07</td>
</tr>
<tr>
<td>Average Characteristic Acceleration (ft/s²)</td>
<td>0.33</td>
<td>0.48</td>
<td>0.46</td>
<td>0.25</td>
</tr>
</tbody>
</table>

![Cluster 1: NREL LA/LB Drayage Creep/Queue Drive Cycle](image1)
![Cluster 2: NREL LA/LB Drayage Port/Near Dock Drive Cycle](image2)
![Cluster 3: NREL LA/LB Drayage Local Drive Cycle](image3)
![Cluster 4: NREL LA/LB Drayage Metro Highway Drive Cycle](image4)
• 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
  o Package delivery trucks
  o School buses
  o Transit buses
  o Utility aerial trucks
  o 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

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Vehicle Systems Program
– Lee Slezak and David Anderson

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www.nrel.gov

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