

Medium- and Heavy-Duty Vehicle Duty Cycles for Electric Powertrains



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NREL Transportation RD&D Activities & Applications

Vehicle Thermal Management

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

Vehicle Deployment/Clean Cities

*Guidance & Information for Fleet Decision
Makers & Policy Makers
Technical Assistance
Online Data, Tools, Analysis*

Vehicle Systems Modeling and Simulation

*Connected and Automated
Vehicles
Vehicle Systems Analysis*

Regulatory Support

*EPAct Compliance
Data & Policy Analysis
Technical Integration
Fleet Assistance*

Infrastructure

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

Advanced Combustion/Fuels

*Advanced Petroleum and Biofuels
Combustion/Emissions Measurements
Vehicle & Engine Testing*

Vehicle and Fleet Testing

*MD/HD Dynamometer Testing
MDV & HDV Testing/Analysis
Drive Cycle Analysis/Field Evaluations
Technology Performance Comparisons
Data Collection, Storage, & Analysis
Analysis & Optimization Tools*

Advanced Power Electronics and Electric Motors

*Thermal Management
Thermal Stress and Reliability*

Advanced Energy Storage

*Development, Testing, Analysis
Thermal Characterization/Management
Life/Abuse Testing/Modeling
Computer-Aided Engineering
Electrode Material Development*



NREL Medium- and Heavy-Duty Fleet Evaluations

This project provides medium-duty (MD) and heavy-duty (HD) test results, aggregated data, and detailed analysis.

- **Third party unbiased data:** Provides data that would not normally be shared by industry in an aggregated and detailed manner
- Over 5.6 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:**
 - Guide R&D for new technology development
 - Help define intelligent use of newly developed technology
 - Help fleets/users understand all aspects of advanced technology



Medium- and Heavy- Vehicle Field Testing Approach

Evaluate the performance of alternative fuels and advanced technologies in MD and HD fleet vehicles in partnership with commercial and government fleets and industry groups vehicles.

Collect, analyze, and publicly report data:

- Drive cycle and system duty cycle analysis
- Operating cost/mile
- In-use fuel economy
- Chassis dynamometer emissions and fuel economy
- Scheduled and unscheduled maintenance
- Warranty issues
- Reliability (% availability, miles between road calls)
- Implementation issues/barriers
- Subsystem performance data & metrics (energy storage system, engine, after-treatment, hybrid/electric vehicle [EV] drive focus)

Data stored in Fleet DNA for security and limited public accessibility

Frequent interactions and briefings with stakeholders – fleets, technology providers, researchers, and government agencies

Fleets

UPS, FedEx, Coke, Frito-Lay, Foothill Transit, PG&E, Miami-Dade, Verizon, Walmart, Waste Management

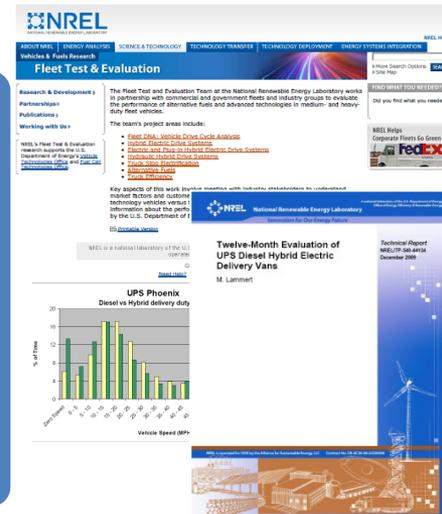
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Vehicle & Equip Mfrs

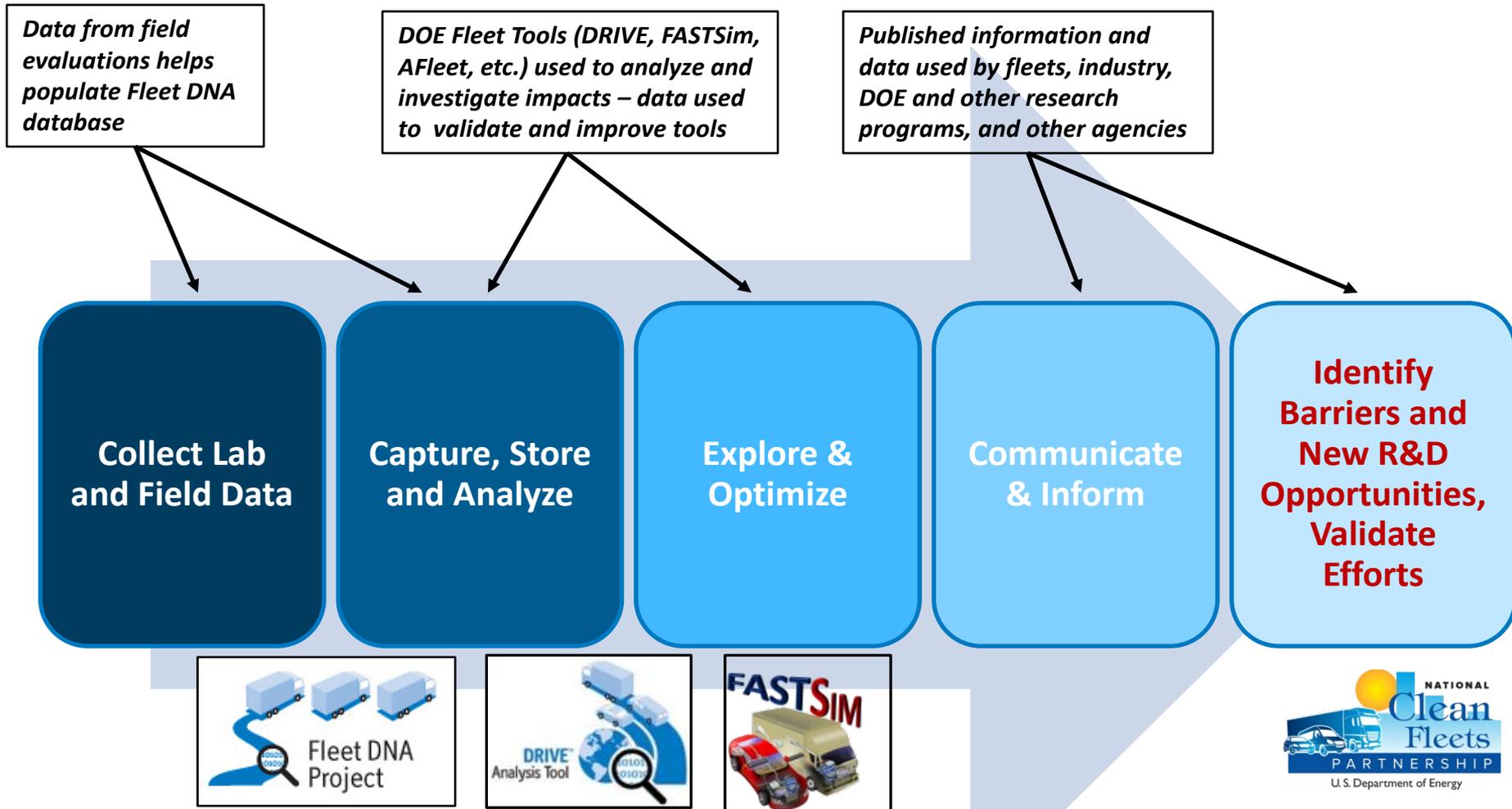
Proterra, Navistar, Smith EV, Eaton, Allison, BAE, EDI, Altec, International, PACCAR, Oshkosh, Odyne, Parker-Hannifin, Cummins

||

Useful Data, Analysis and Published Reports



NREL Field Data & Analysis Tools



Partnership with Fleets and Technology Providers = Relevant Results & Optimized Solutions for Real World Applications

Medium- and Heavy-Duty EV Data Collection



Foothill Transit EV
 12 Proterra EV transit buses
 Eaton 500-kW fast charger

- Dedicated EV bus route in West Covina, CA
- 1-Hz data from over 92,000 miles of transit bus EV driving

Vehicle Specifications:	
Weight	Class 8
Motor Power (peak / continuous)	220 kW / 120 kW
Battery Size	88kWh
Transmission	2 Speed



EV Delivery Trucks
 459 Smith Newton EVs
 Distributed around U.S.

- Frito-Lay, Staples, FedEx, Coca Cola, AT&T, PG&E
- 1-Hz data from over 5 million miles of commercial EV driving
- Detailed Frito-Lay field study

Vehicle Specifications:	
Weight	Class 6
Motor Power (peak / continuous)	150 kW / 80 kW
Battery Size	80/120 kWh
Transmission	Single Speed



Port of LA – EV Drayage
 Class 8 tractor trailers
 TransPower and US Hybrid

- Servicing Port of LA and surrounding distribution centers
- 1-Hz data from over 24,000 miles of commercial EV driving (on-going)

Vehicle Specifications:	
Weight	Class 8
Dual Motor Power (peak / continuous)	300 kW / 240 kW
Battery Size	269 kWh
Transmission	10 speed AMT



EV Delivery Vans
 101 class 2-3 electric vans
 Distributed around U.S.

- Deployments include:**
- FedEx, Cascadia Dealer, PG&E
 - 1-Hz data from over 353,000 miles of commercial EV driving

Vehicle Specifications:	
Weight	Class 2-3
Motor Power (peak / continuous)	70 kW / 55 kW
Battery Size	80kWh
Transmission	Single Speed

EV Vehicle and Component Data – 1 Hz

Vehicle Data Parameters

Vehicle ID
Vehicle weight or mass
Payload
Door status
Timestamp
Operation state
Shifter position
Transmission gear state (if applicable)
Accelerator position
Brake pedal on state or applied pressure
Vehicle speed
Distance driven
GPS latitude
GPS longitude
GPS elevation
Ambient temperature
Air conditioner state
Air conditioner compressor power
Heater state
Air compressor status / pressure

Component Data Parameters

Battery current
Battery voltage
Battery pack SOC
Battery pack min cell voltage
Battery pack max cell voltage
Battery pack balance mode state
AC charging current
AC charging voltage
Battery pack bulk temperature
Battery pack min cell temperature
Battery pack max cell temperature
Motor temperature
Power electronics/charger temperature
DC/DC voltage
DC/DC current
Motor speed
Motor torque
Motor power (electrical)

EV Transit Bus Example:

Foothill Transit / Proterra EV Transit Bus

Vehicle Specifications

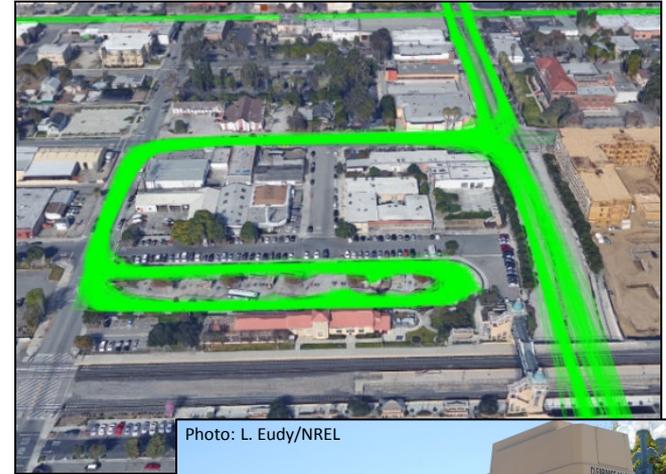
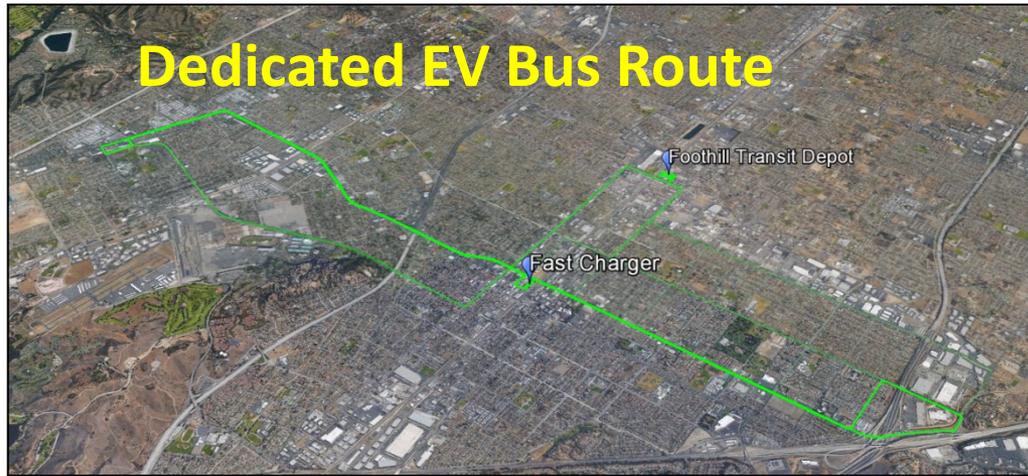
Length (feet)	35
Curb Weight (lb)	27,680
GVWR (lb)	37,320
Capacity (passengers)	35 Seated / 18 Standing



Electric Drive System

Battery (Mfr / Model)	Altairnano - TerraVolt 368
Battery Type	368 V lithium titanate
Battery (Energy/Capacity)	88 kWh / 60 Ah
Number of Packs	(8) 6-floor, 2-roof
Motor (Mfr / Model)	UQM / PP220
Motor Power (kW)	120 Nominal / 220 Peak
Fast Charging Power (kW)	500

Foothill EV Bus Route & Duty Cycle Overview



Bus Daily Drive Cycle Statistics

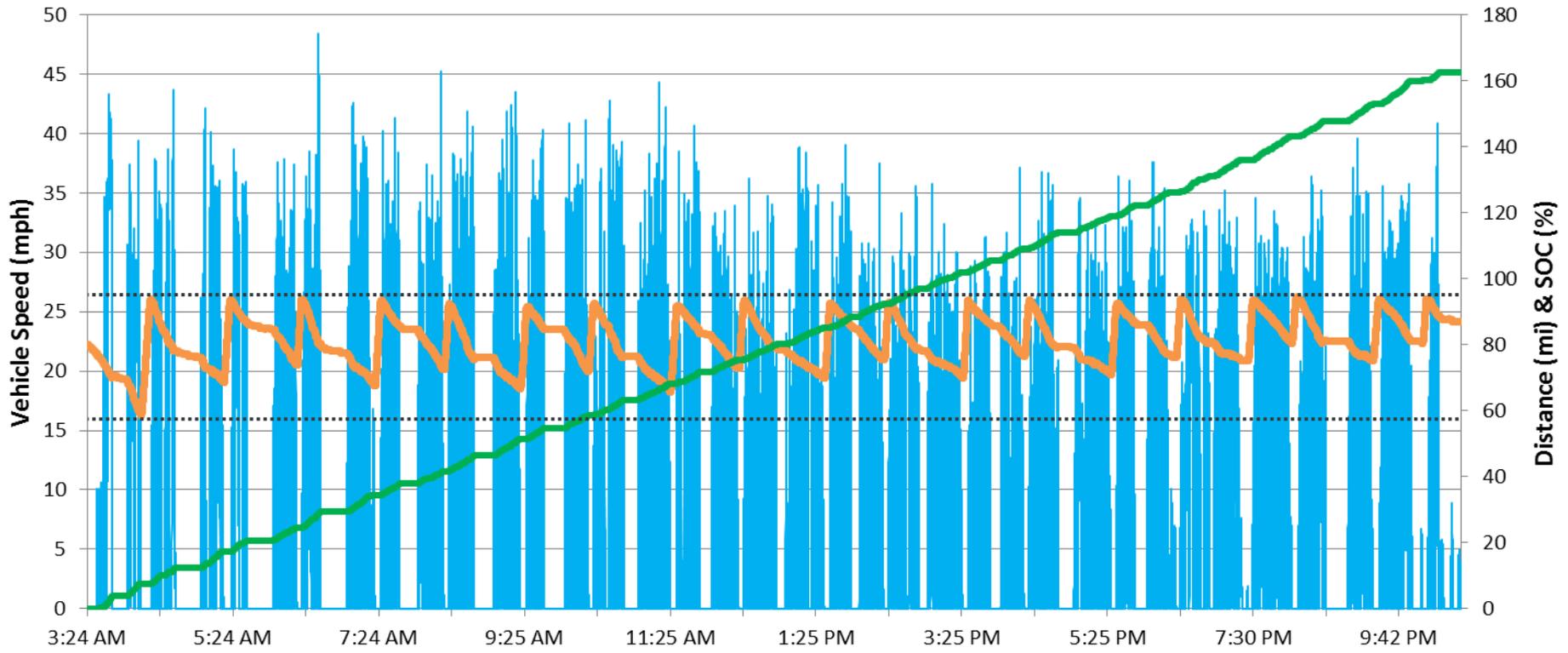
Metric	Foothill Transit (n=774)	Fleet DNA (n=472)
Average Speed <i>incl. speed = 0</i> (MPH)	8.42 mph	11.46
Average Driving Speed (MPH)	17.66	20.89
Average Kinetic Intensity (1/mi)	1.71	1.86
Average Stops per Mile	3.70	2.04
Average Number of Stops per Day	444.29	213.89
Average Distance Traveled (miles)	119.30	108.06
Daily Hours of Operation (hours)	13.9 total / 6.72 driving	9.54 total / 5.34 driving
Average Acceleration (ft/s ²)	1.44	1.34
Average Deceleration (ft/s ²)	-1.81	-1.36
Percent of total time Charging	5.56%	N/A

Typical Daily Operation

Vehicle Speed, SOC & Distance

VIN: 816048 - May 4, 2015

— Vehicle Speed — SOC — Distance

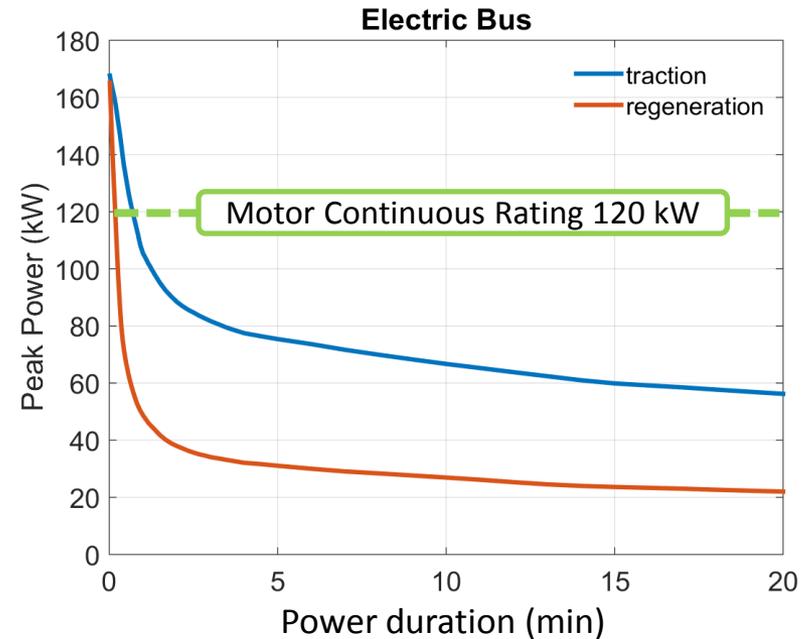
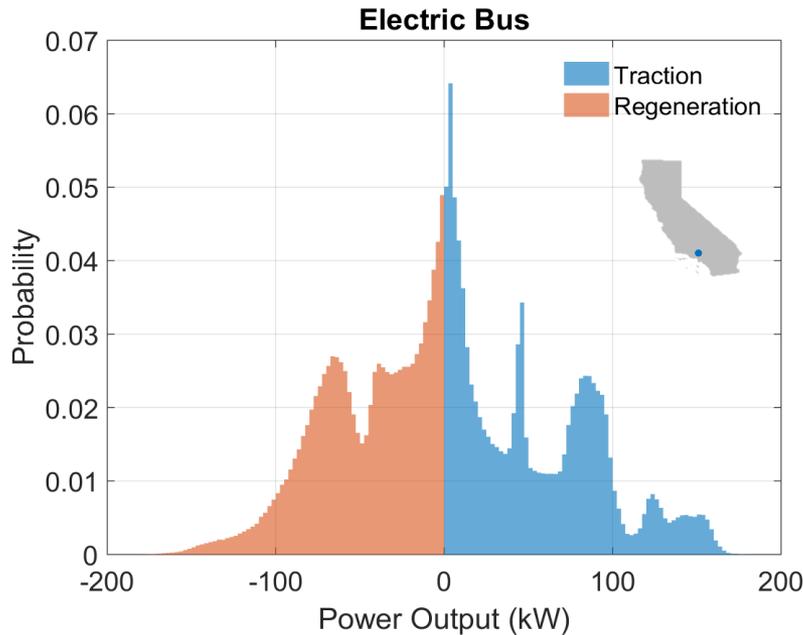


SOC: state of charge

Kinetic Intensity (KI)

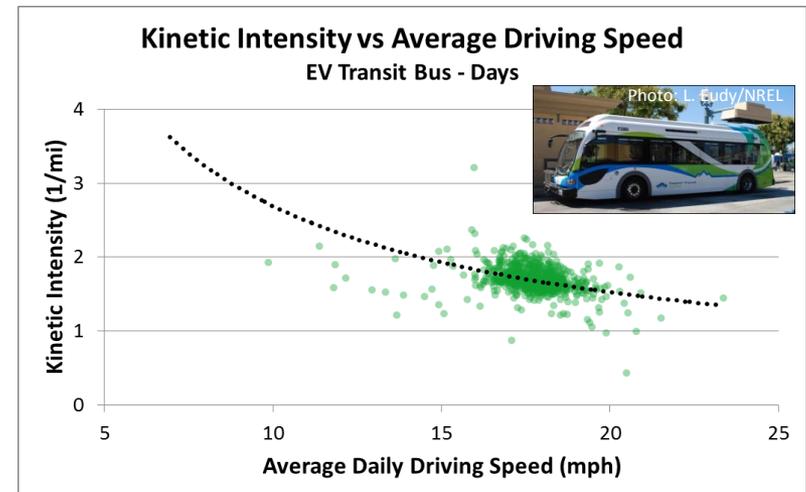
- **Kinetic Intensity is measure of drive cycle kinetics to define how much “*stop and go*” is in the cycle**
 - Derived from ratio of aerodynamic speed and characteristic acceleration
 - Characteristic acceleration: Measures the inertial work to accelerate and/or raise the vehicle per unit mass per unit distance over the cycle.
 - Aerodynamic speed: Measures the ratio of the overall average cubic speed to the average speed

EV Bus In-Use Motor Power Characteristics

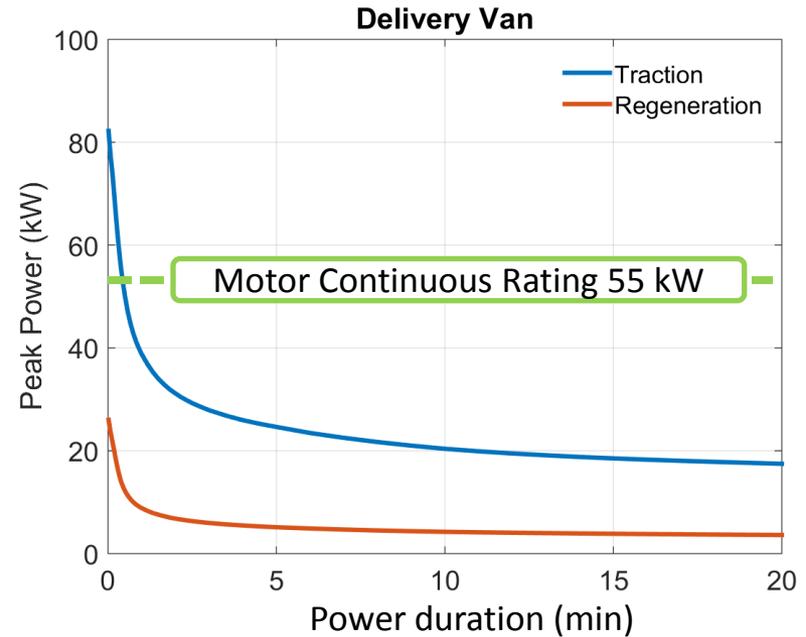
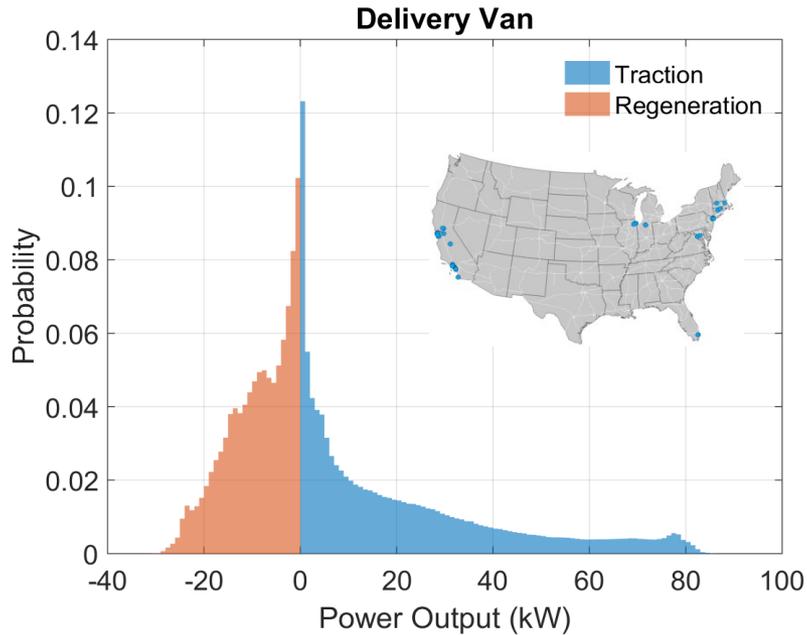


Duty Cycle Statistics

Driving days	774
Kinetic intensity (1/mi)	1.71
Stops per mile	3.70
Avg acceleration (ft/s ²)	1.44
Avg speed (mph)	17.66

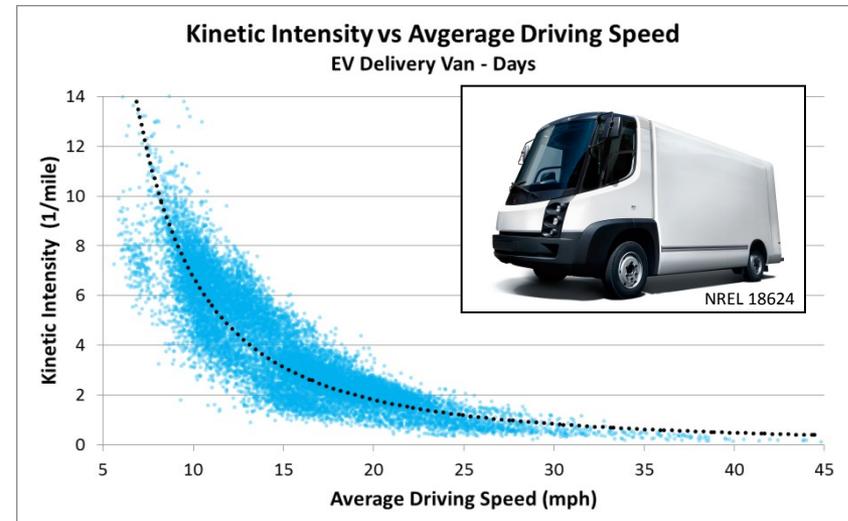


Delivery Van (Class 3)

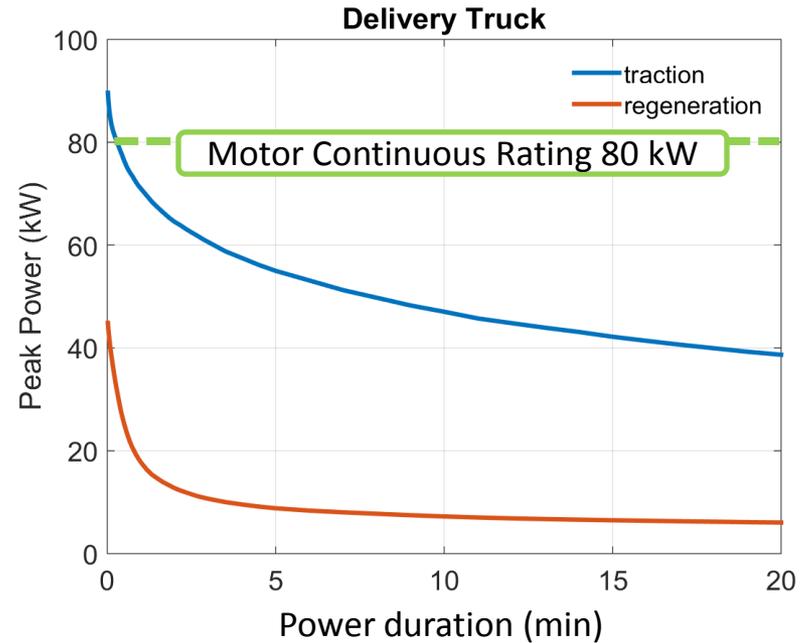
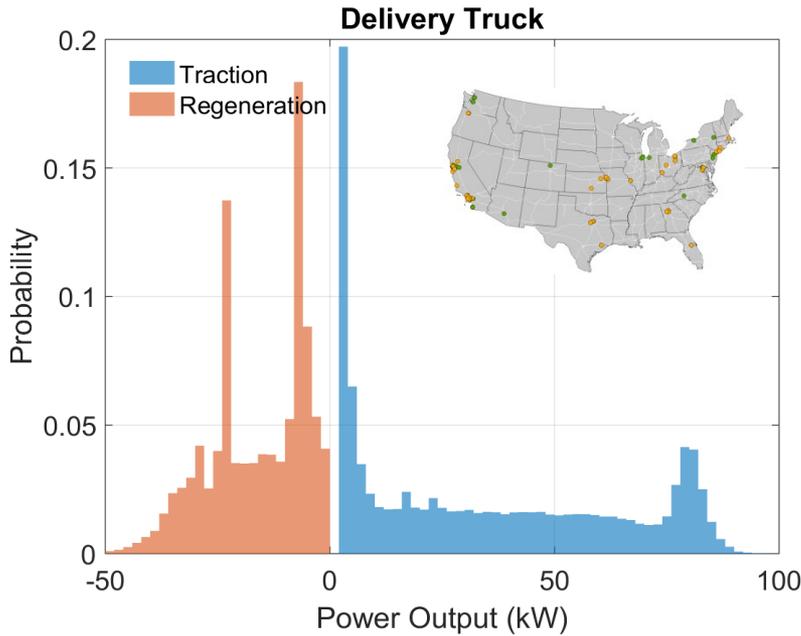


Duty Cycle Statistics

Driving days	17,447
Kinetic intensity (1/mi)	3.85
Stops per mile	5.85
Avg acceleration (ft/s ²)	0.52
Avg speed (mph)	15.6

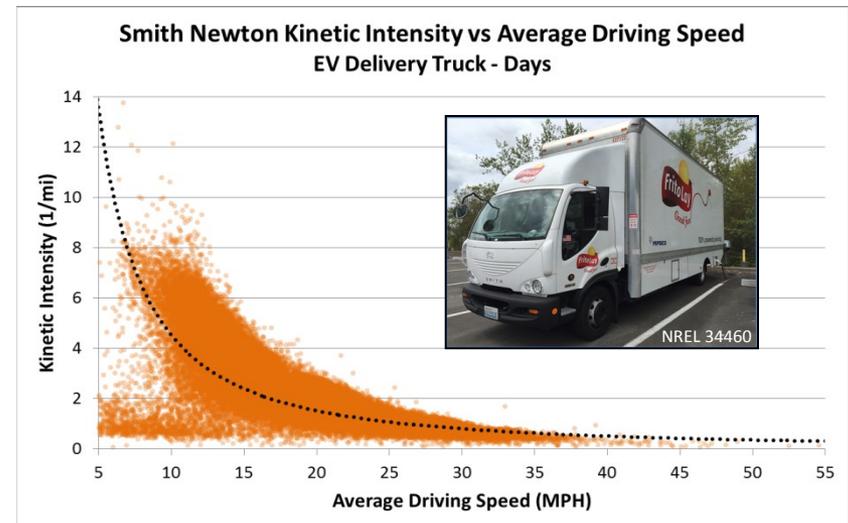


Delivery Truck (Class 6)

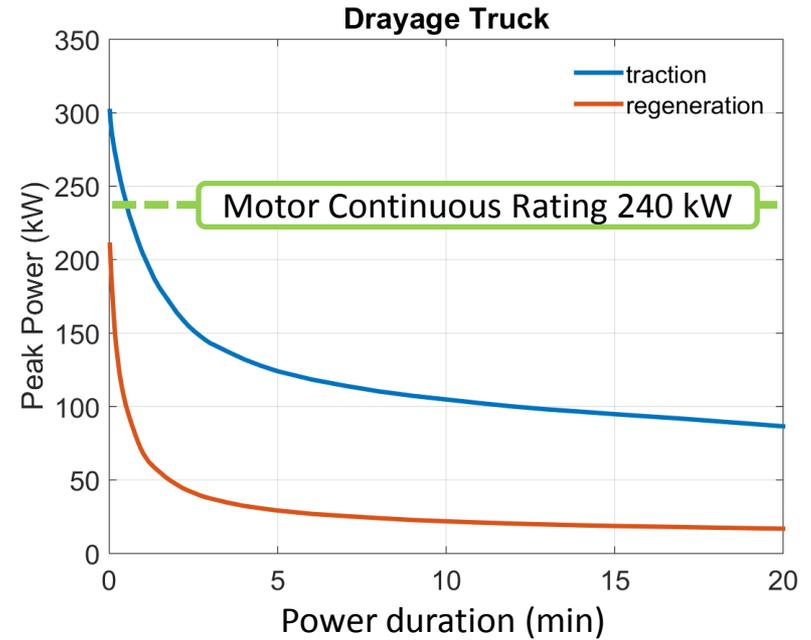
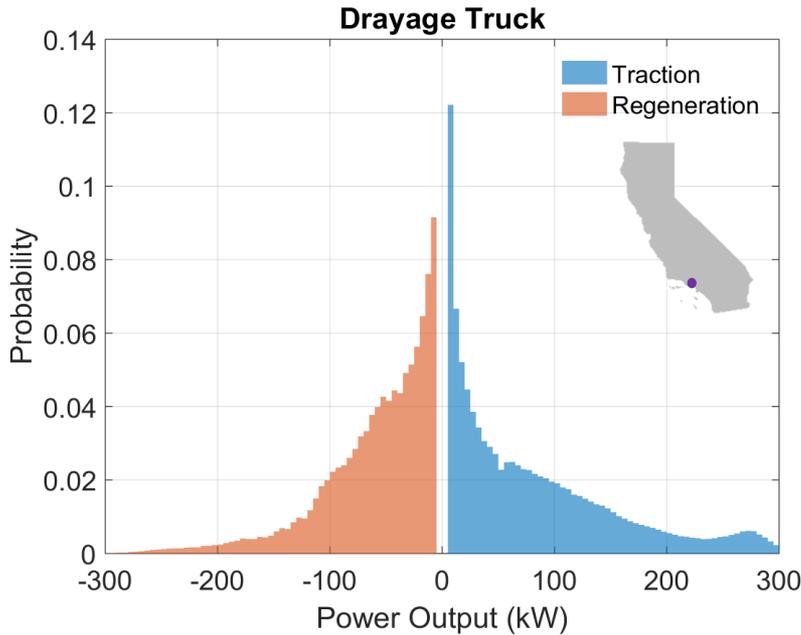


Duty Cycle Statistics

Driving days	173,007
Kinetic intensity (1/mi)	1.78
Stops per mile	2.03
Avg acceleration (ft/s ²)	1.01
Avg speed (mph)	21.6

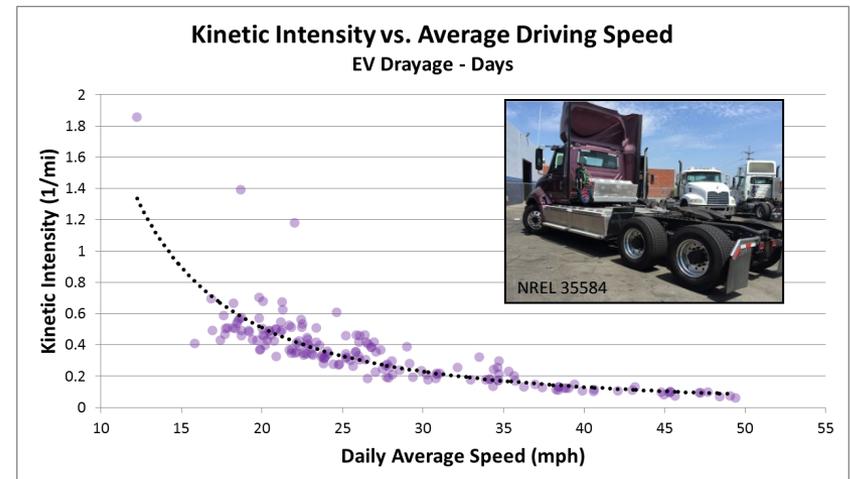


Drayage Truck (Class 8)

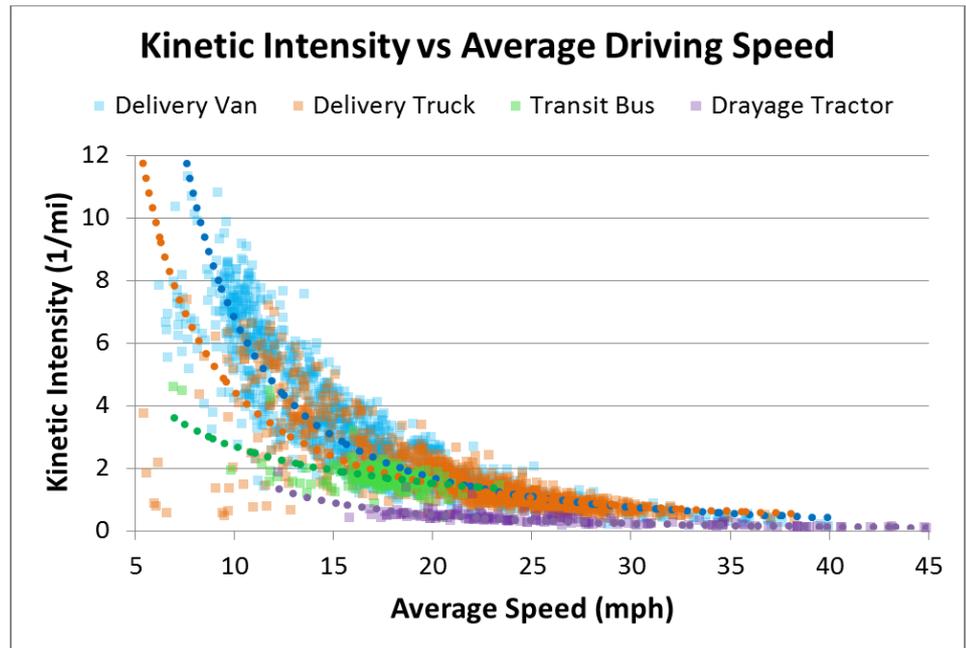
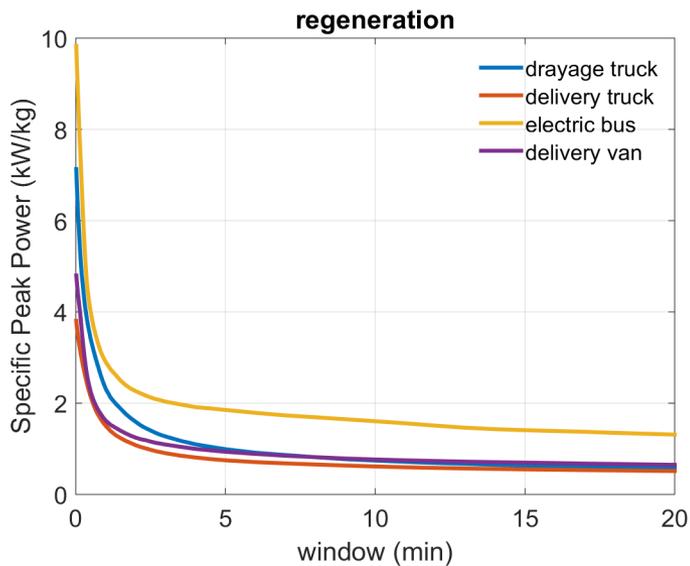
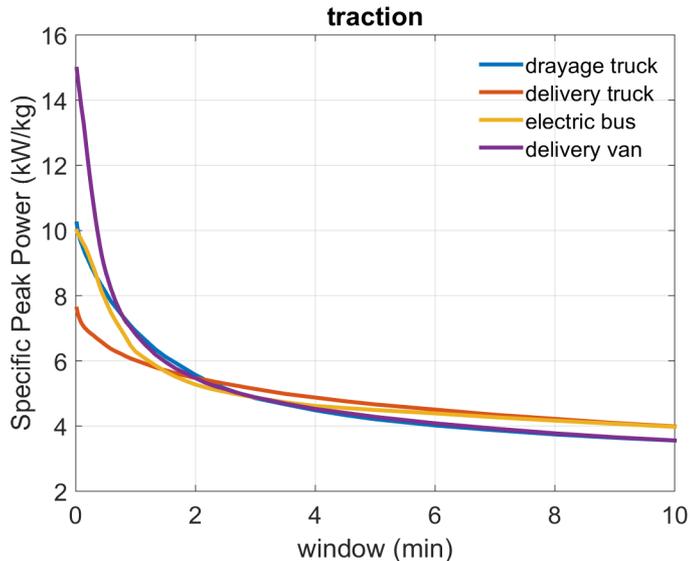


Duty Cycle Statistics

Driving days	173
Kinetic intensity (1/mi)	0.96
Stops per mile	1.18
Avg acceleration (ft/s ²)	0.84
Avg speed (mph)	27.4



Aggregate



- Delivery van has the highest peak traction power per vehicle mass
- Transit bus has the highest peak regeneration power per vehicle mass
- Delivery van was driven most aggressively, while the bus had the least variation in duty cycle.

Summary

- Understanding the vocational duty cycle is critical for appropriate sizing of EV components for MD and HD plug-in EV applications. NREL has extensive in-use data
- NREL field data show the ratio between peak power and continuous power requirements varies by vocation (**motor specs shown in blue**)
 - Transit Bus ~ 160 kW / 60 kW (2.7) | **220 kW / 120 kW (1.8)**
 - Delivery Van ~ 70 kW / 55 kW (4.0) | **70 kW / 55 kW (1.3)**
 - Delivery Truck ~ 90 kW / 40 kW (2.3) | **150 kW / 80 kW (1.9)**
 - Class 8 Drayage Tractor ~ 300 kW / 90 kW (3.3) | **300 kW / 240 kW (1.25)**
- The transit bus and drayage truck data showed symmetric distributions of traction and regeneration power usage profiles.
- Power electronics must be designed to handle power and heat requirements for both traction and regenerative power.
- Additional evaluation of NREL commercial EV data will be conducted and published in 2016.

Additional Information

Available through Fleet DNA
www.nrel.gov/fleetsdna

Objectives:

- Capture and quantify drive cycle and technology variations for the multitude of **medium- and heavy-duty** vocations
- Provide a common data storage warehouse for medium- and heavy-duty vehicle data across DOE activities and labs – www.nrel.gov/fleetsdna
- Integrate existing DOE tools, models, and analyses to provide data-driven decision-making capabilities

For Government: Provide in-use data for standard drive cycle development, R&D, tech targets, and rule making

For OEMs: Real-world usage datasets provide concrete examples of customer use profiles

For Fleets: Vocational datasets help illustrate how to maximize return on technology investments

For Funding Agencies: Reveals ways to optimize impact of financial incentive offers

For Researchers: Provides a data source for modeling and simulation

Fleet DNA: Commercial Fleet Vehicle Operating Data

The Fleet DNA clearinghouse of commercial fleet vehicle operating data helps vehicle manufacturers and developers optimize vehicle designs and helps fleet managers choose advanced technologies for their fleets. This online tool provides data summaries and visualizations similar to real-world "genetics" for medium- and heavy-duty commercial fleet vehicles operating in a variety of vocations.



This project supports the development and deployment of market-ready advanced vehicle technologies.

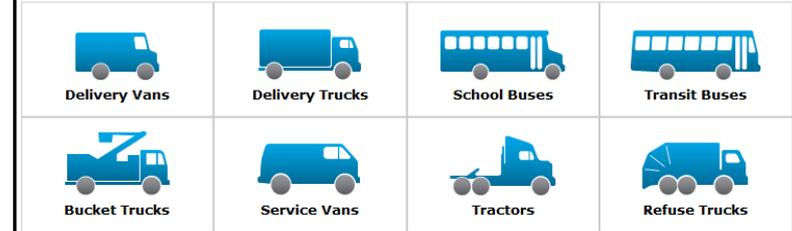
Contribute Data

Learn how to [contribute to Fleet DNA](#) anonymously to help other fleets analyze and improve their drive cycle metrics.

For more information, refer to the [Fleet DNA fact sheet](#).

Data by Vehicle Category

View and download data, charts, and reports by vehicle category.



Composite Data for All Categories

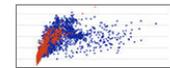
View charts with data for all the vehicle categories above or download the [composite data for all vehicles](#). Fleet DNA has 4,705 days of driving data from 486 vehicles operating in the United States.



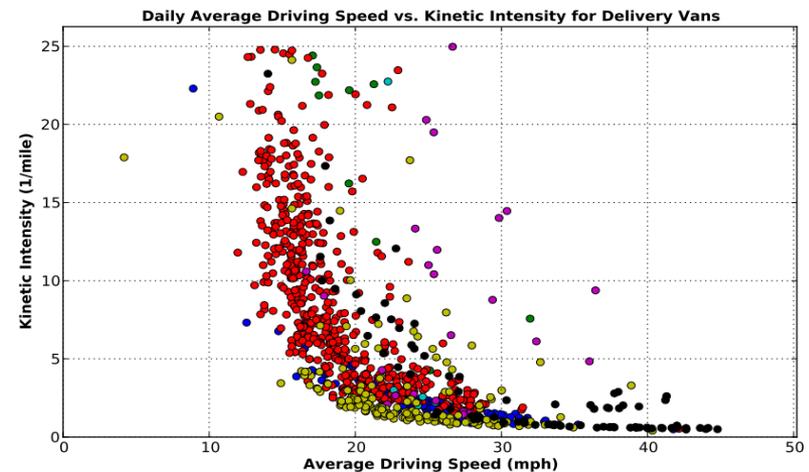
Daily Average Driving Speed and Kinetic Intensity for All Vehicle Categories



Daily Stops per Mile Distribution for All Vehicle Categories



Average Acceleration and Number of Stops for All Vehicle Categories



Thank You!

Questions/Discussion

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