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NATIONAL RENEWABLE ENERGY LABORATORY

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Vehicle Modeling & Data Analysis: Transportation Secure Data Center (TSDC), FleetDNA and the Future Automotive Systems Technology Simulator (FASTSim)

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RELEVANCE

- Relevant EEMS Program Strategic Goals*
  - Develop tools, techniques, and core capabilities
  - Share research insights and capabilities with stakeholders
- Addressing EEMS Program Barriers*
  - *Difficulty sourcing real-world data on vehicles and travelers in the transportation system* – access to historic and present-day data is critical for real-world scenario evaluation and for model validation and calibration
  - *Difficulty accurately modeling large-scale systems and comprehensive scenarios* – an agile vehicle model that accurately captures the most important factors impacting energy consumption enables cost-effective exploration of wide-ranging scenarios and rapid, open-source/replicable application to large-scale real-world travel data (by anyone)
  - *Need for tools/techniques/insights at vehicle, traveler and system level, and sharing these* – the data and models are free of license costs and 3rd party software requirements, and are available through NREL's website (along with many publications by researchers who have used them).

*Anderson, David. "Energy Efficient Mobility Systems: EEMS Program Vision, Mission, Goals & Barriers." Slide presentation of information for EEMS Program Annual Merit Review Presenters. January 30, 2018.

OBJECTIVES & MILESTONES

- Objectives
  - Work with partners to obtain and analyze real-world data for personal travel (in light-duty vehicles and other modes) and commercial vehicle travel behavior
  - Couple real-world travel insights with agile modeling to evaluate large-scale scenarios
    - Long-running NREL competency, additionally applicable to off-cycle credits analysis
  - Make research insights openly available, along with supporting data and tools
    - Enable independent replication and extension of research by external stakeholders.

SUMMARY

Date	Milestone/Deliverable	Status
Quarterly	Quarterly progress updates	On-track/ongoing
March 2018	Report on enhancements to the Future Automotive System Technology Simulator (FASTSim) and data updates to the Transportation Secure Data Center (TSDC)	Complete
October 2018	Annual Report on Vehicle Technology Evaluations and Fleet DNA	On-track

- TSDC, Fleet DNA, and FASTSim are valuable EEMS resources
  - Real-world data and analysis capabilities for assessing present-day and potential future vehicle/transport energy consumption and performance
- Accessible to lab and external researchers
  - Emphasis on maximizing data/information accessibility within constraints of protecting individual privacy and commercially sensitive data
  - Open source, and free of license costs and 3rd party software expenses
- Combination of resources enables agile, large-scale evaluations
  - Emphasis on validation and real-world data for credibility
  - Focus on most influential effects and fidelity needed for a given task → facilitates broad, cost-effective scenario evaluations
- Numerous application examples, including:
  - With DOE for advanced powertrain, connected/automated vehicle, and alternative fueling infrastructure evaluations
  - With industry partners for impact assessments of off-cycle technology and alternative powertrain design scenarios.

TSDC

APPROACH

TSDC was established in 2009 because of increasing collection of **high-resolution travel data** (e.g., GPS trajectories, geo-coded trip ends) in surveys/studies

- Jointly supported by DOT FHWA and DOE VTO
- Data are very valuable for energy and travel research, but misuse could violate individual privacy.

Secure data center makes data available for legitimate research while preserving privacy of participants

- Maximizes value from limited public funds
- Benefits data providers and users
  - Alleviates burden of archiving data and responding to data requests
  - Data accessible from a central location.

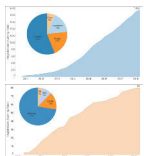
TSDC operating procedures include

- **Public website** for downloading cleansed data sets
- **Secure portal** for approved users to work with detailed spatial data
- Advisory committee to support oversight, setting procedures, and reviewing data access applications.

DOT: U.S. Department of Transportation
FHWA: Federal Highway Administration
GPS: global positioning system
VTO: Vehicle Technologies Office

ACCOMPLISHMENTS: TSDC DATA SETS AND WEB ACCESS

- The TSDC continues to see substantial growth in the number of external users accessing the resource
- Access to the data enabled publication of ≈30 research papers in 2017 alone
- Relevant research applications include:
  - Real-world driving and parking profiles used to inform siting of charging infrastructure for potential future electrified vehicle market penetration scenarios
  - Analyzing prevalence of driving conditions detrimental for vehicle emissions control (in collaboration with industry partners).



FleetDNA

APPROACH

Fleet DNA was established in 2012 to:

- 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 fleet data across DOE activities and labs
- Integrate existing DOE tools, models, and analyses to provide data-driven decision making capabilities.

Fleet DNA operating procedures include:

- **Public website** for downloading aggregated duty cycle statistics by vehicle vocation and weight class
- **Secure database** for storage and protection of raw data
- **Fusion of data** with other data sets—chassis dynamometer, road network, road grade, weather, vehicle specifications, vehicle registration data
- **Integration with analysis tools** – FASTSim, DRIVE
- **Advanced analytics** and high-performance computing
- **Applications** and new data sources in partnership with industry, government, and research partners.

DRIVE: Drive-Cycle Rapid Investigation, Visualization, & Evaluation tool

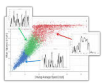
www.nrel.gov/fleetdna

Screen shot of Fleet DNA public website where anonymized, aggregated duty cycle statistics and data can be downloaded

ACCOMPLISHMENTS: FLEET DNA DATA AND ANALYSIS

- Fleet DNA features 11.5 million miles of 1-Hz engine controller area network, GPS, and component data from 1,700 vocational vehicles operated by fleet partners—***UPS, FedEx, Coke, Frito-Lay, Foothill Transit, PG&E, Verizon, Walmart, Waste Management, Port of Long Beach, and more.***
- NREL has applied multi-variate data analysis, data fusion, and visualization techniques—such as principal component analysis and hierarchical clustering—to assist industry partners in optimizing advanced powertrains.
- Fleet DNA helps users understand the broad operational range of commercial vehicles across vocations, technologies, and weight classes.
- The data-driven insight and decision-making capabilities facilitated by Fleet DNA support a variety of DOE research activities and industry partnerships.
- Recent industry partners: ***Cummins, PACCAR, Peterbilt, Ford, GM, Proterra, Navistar, Eaton, Allison, Bosch, Odyne, Smith EV, BAE Systems, Efficient Drivetrains, Blossman, TransPower, Blue Bird, ORNL, EPA, ARB, SCAQMD, and TARDEC.***

Map showing freight volumes (red) along major U.S. roadways and Fleet DNA data coverage (blue) along those routes.



Samples of representative drive cycles and electric bus power demand data

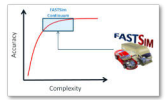
FASTSim

APPROACH

FASTSim balances accuracy vs. complexity

- Model captures most important factors influencing vehicle fuel economy, performance, and cost (including powertrain technology, vehicle and component sizes, how the vehicle is driven, etc.)

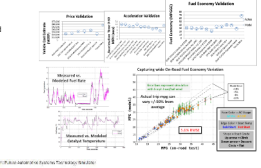
FASTSim itself occupies a continuum, varying the accuracy vs. complexity tradeoffs



Level of Modeling	Strengths	Limitations
Standard Option		
• Default power vs. efficiency maps for each component	• Fastest to calibrate; requires small amount of public vehicle information	• Captures most important factors for high-level comparisons, but lacks detail for focused studies on a specific vehicle.
• Maps scaled based on component power ratings for modeled vehicle.	• Suitable for large-scale simulation/ evaluation of thousands of vehicle designs.	
Customized Option		
• Vehicle-specific component calibration.	• Provides more precise model of specific vehicle(s).	• Larger calibration burden; requires detailed component-level data from manufacturer or testing.
Potential Extensions for Targeted Investigations		
• Temperature dependence	• Even more detail for studies that need it	• Further raises calibration burden
• Torque vs. speed disaggregation	• Precise validation in numerous dimensions and conditions.	• Still not suitable for applications requiring real-time control (e.g., hardware-in-the-loop testing).
• Shift schedules		

ACCOMPLISHMENTS: FASTSIM VALIDATION AND RESOURCE AVAILABILITY

- Website: Excel and Python versions available for download (free & open source)
- FASTSim Validation Report, and additional publications using the tool
- Interactive demo development and starter code
- Summary fact sheet.

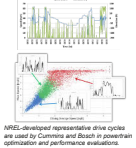


FASTSim: Future Automotive Systems Technology Simulator

Example Application Accomplishments

MEDIUM-DUTY RANGE-EXTENDED ELECTRIC VEHICLES

- Leveraging Fleet DNA data to characterize real-world duty cycles from urban delivery vehicles, NREL applied the k-medoid clustering algorithm to segment in-use driving profiles into operational modes and developed representative drive cycles for various modes using the DRIVE tool.
- NREL developed analytical methods to incorporate other parameters, such as road grade and idle time, into drive cycles.
- NREL's drive cycles are being used to size drivetrain components to meet performance requirements and validate performance relative to program objectives.
- NREL's reusable methodology has been applied in a range of vehicle vocations, including Class 8 drayage trucks at the Port of Long Beach.



NREL-developed representative drive cycles are used by Cummins and Bosch in powertrain optimization and performance evaluations.

REAL-WORLD DRIVE CYCLE DEVELOPMENT AND APPLICATIONS

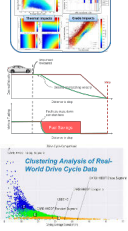
- NREL's DRIVE tool uses GPS and controller area network data to characterize vehicle operation and produce statistically representative drive cycles based on real-world activity.
- DRIVE analyses cover 168 unique drive-cycle metrics to generate custom representative drive cycles from "ideal" sections of filtered data using specialized statistical clustering methods.
- The Drive-Cycle Analysis Tool (DriveCAT) provides an inventory of downloadable vocational drive cycles for use by industry and researchers.

DRIVE's user interface displaying speed versus time plots of source data, cleansed data, and custom drive-cycle data.

DriveCAT website where industry standard and NREL-developed drive cycles can be downloaded.

COMBINED FASTSIM AND TSDC/FLEETDNA APPLICATION EXAMPLES

- Segregation and analysis of vehicle speed profiles in different driving conditions, and simulation for different vehicle/powertrain types
  - Used to train energy estimation modeling for green routing and aggregate "off-cycle" technology impact assessments, including for connected and automated vehicles
- Large-scale screening of prospective vehicle dynamics and powertrain control strategies prior to implementation by major automaker
- Opportunity assessment for commercial vehicle electrification
  - Worked with multiple industry partners to optimize hybrid electric vehicle, electric vehicle, and range-extended electric vehicle powertrain requirements using FASTSim models simulated across a distribution of real-world vocational drive cycles and operational modes from Fleet DNA.



REMAINING CHALLENGES & BARRIERS + PROPOSED FUTURE RESEARCH ADDRESSING THEM

- New technologies & mode options will change travel behavior
  - Propose identification, collection, and inclusion of new/on-going data in TSDC and Fleet DNA capturing these changes as they occur
- New sources of travel data becoming available
  - Propose starting to include large-scale probe data from various sources as a complement to dedicated individual vehicle/traveler data collection
- Research effectiveness constrained by tool/feature updates
  - Propose pushing out updates to benefit all resource users, e.g.:
    - For TSDC and Fleet DNA – access to enhanced computational resources in addition to data
    - For FASTSim – updating with latest available vehicle models, and making new/in process feature enhancements broadly available (such as models of entire light-duty fleet, generalizing real-world thermal effects and impacts of latest technology enhancements on engines and other components).

Any proposed future work is subject to change based on funding levels.

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

- The organizations listed below, along with university/lab researchers and others, include partners for obtaining data and consumers of data, insights, and capabilities provided by the resources.

Collaboration/coordination partners and activities include (further details in back-up slides of the corresponding presentation):

- DOT FHWA: Jointly support the TSDC with DOE VTO
- Many MPOs and State DOTs: Contribute data from travel surveys and studies from their regions into the TSDC
- Other federal/state/local agencies: Leverage the resources
- Fleet Operators: Partner on vehicle instrumentation to collect use and performance data in specific applications; also consumers of data, insights, and capabilities provided by the resources
- Manufacturers and Suppliers: Often support vehicle instrumentation; also consumers of data, insights, and capabilities provided by the resources
  - Implications of real-world demands on component design
  - Distribution of performance and efficiency at large scale
  - Estimating "off-cycle" technology benefits
  - Analyzing frequency of emissions-challenging driving conditions.

MPO = Metropolitan Planning Organization

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