Georgia Tech College of Engineering School of Civil & Environmental Engineering

GEORGIA TRANSPORTATION INSTITUTE

Integrating Transportation, Energy, and Emissions Modeling Across Spatial and Temporal Scales

National Center for Sustainable Transportation

arpa·e CHANGING WHAT'S POSSIBLE

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Georgia Institute of Technology
School of Civil and Environmental Engineering

NCST Webinar
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12/4/2019

Overview

- Modeling Tools
  - MOVES-Matrix for energy and emissions
  - Georgia Tech Fuel and Emissions Calculator (FEC)
- Application Linkages
  - Travel demand and activity-based modeling (ABM)
  - Traffic simulation models (Vissim™, DTA, etc.)
  - Data-driven real-time simulation
  - Monitored corridor-level vehicle activity
  - Pollutant dispersion models (AERMOD, etc.)
- Ongoing modeling work (dissertations)

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MOVES Modeling

$$VSP = \left(\frac{A}{M}\right)v + \left(\frac{B}{M}\right)v^2 + \left(\frac{C}{M}\right)v^3 + \left(\frac{m}{M}\right)(a + g * \sin\theta)v$$

- EPA's Motor Vehicle Emissions Simulator (MOVES)
- Emissions are defined as a function of speed and vehicle-specific power (VSP) to account for the impact of speed and acceleration on energy and emissions
- MOVES translates inputs into the VSP framework, processes the inputs, and translates results back into user-required outputs

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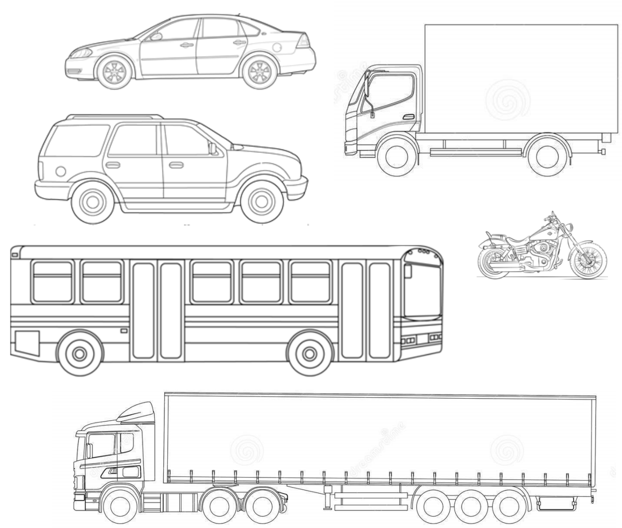
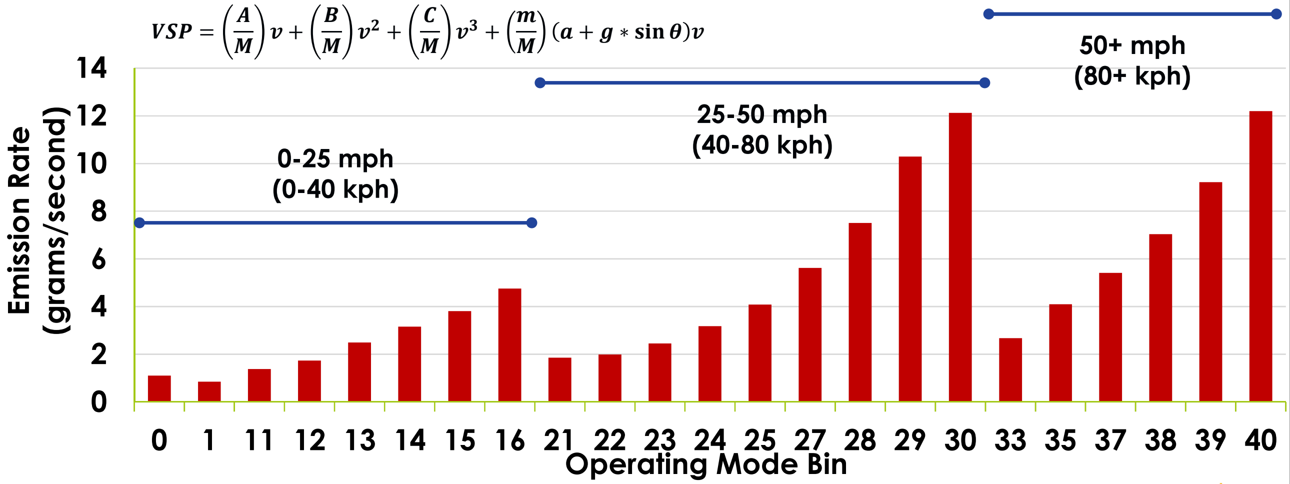
13 MOVES Source Types

Source Type Name	Source Type ID
Motorcycle	11
Passenger Car	21
Passenger Truck	31
Light Commercial Truck	32
Intercity Bus	41
Transit Bus	42
School Bus	43
Refuse Truck	51
Single-Unit Short Haul Truck	52
Single-Unit Long Haul Truck	53
Motor Home	54
Combination Short Haul Truck	61
Combination Long Haul Truck	62



Example CO_2 Emission Rates by OpMode Bin for Passenger Trucks (2016MY in 2016)

$$VSP = \left(\frac{A}{M}\right)v + \left(\frac{B}{M}\right)v^2 + \left(\frac{C}{M}\right)v^3 + \left(\frac{m}{M}\right)(a + g * \sin\theta)v$$



23 operating mode bins
0 = braking, 1 = idle, 11 = coast, 21 = coast

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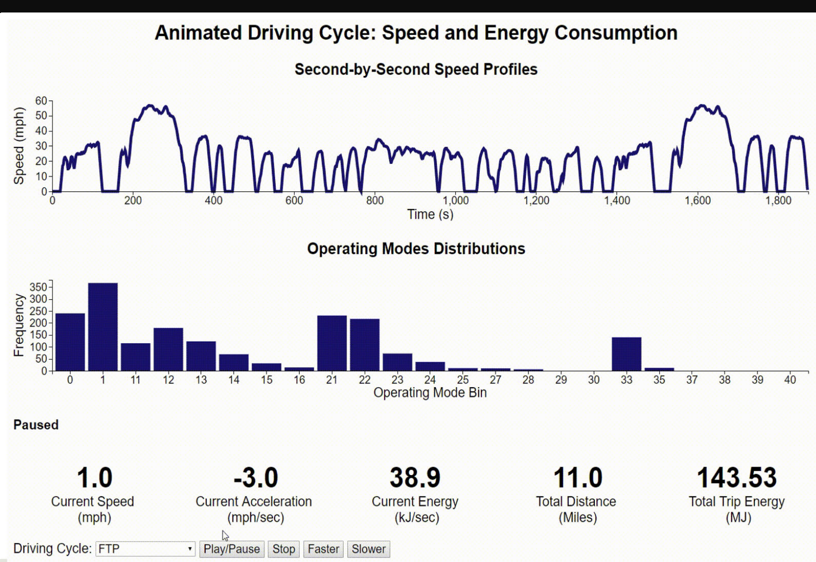
FTP Driving Cycle



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Traditional MOVES Modeling

- Modeling of complicated and dynamic networks is tedious
  - Requires generation of many link emission rates
  - Users often create lookup tables to support modeling
- GT Goal: Pre-run MOVES for all combinations of input data
  - Configure MOVES for distributed computing
  - Iterate runs across all input combinations
  - Compile emission rates into a multi-dimensional matrix
  - Develop scripts to apply these matrices to analyses

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MOVES Runs per Region

- 30,429 MOVES on-road exhaust runs
  - 21 calendar years
  - 3 fuel months (summer, winter, transition)
  - 23 temperature bins (5°F bins)
  - 21 humidity bins (5% bins)
- 20 minutes/core/run
  - Five days in PACE (80+ sustained cores assigned)
- 5,348,983,500 running emission rates per region
- 121.2 Gb emission rate matrix per region
- More than 1 million MOVES runs to date

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Partnership for an Advanced Computing Environment (PACE)

- Partnership between Georgia Tech faculty, researchers, and the Georgia Tech Office of Information Technology
  - 35,000 cores
  - 90 terabytes memory
  - 2 petabytes of storage

The PACE "Super" Computer

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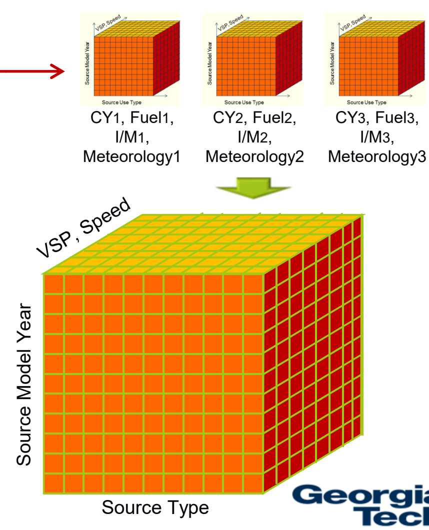
MOVES-Matrix Run Module: Developing On-Road Fleet Emission Rates

Regional Matrix

Regional Inputs: Calendar Year, Fuel, I/M, Meteorology

Select sub-matrices



Fleet Activity per Link: Source Type Distribution, Model Year Distribution, Speed / VSP OpMode Bin

Query sub-matrix →

← Return fleet emission rate (weighted by onroad activity)

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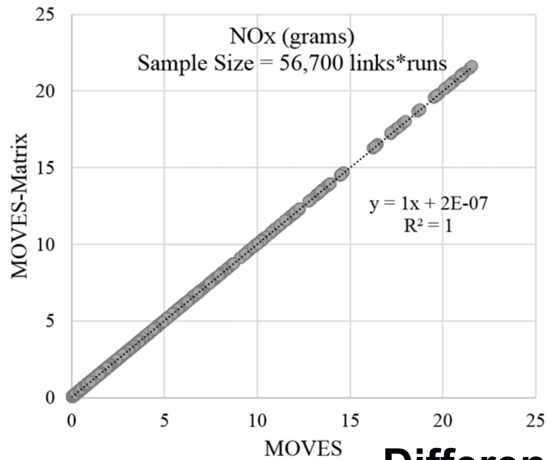
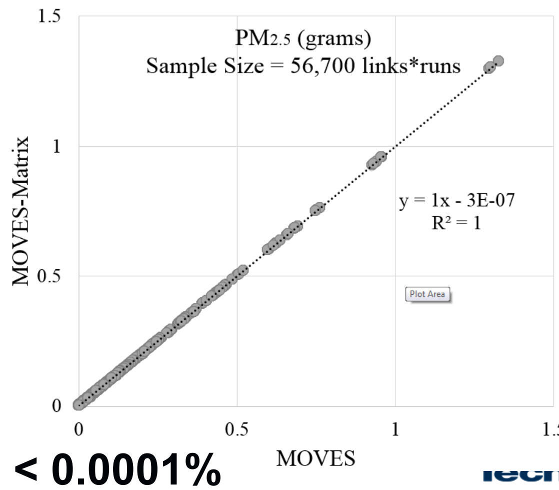
MOVES vs. MOVES-Matrix Results

- ➢ Results are exactly the same as MOVES GUI results





Difference < 0.0001%

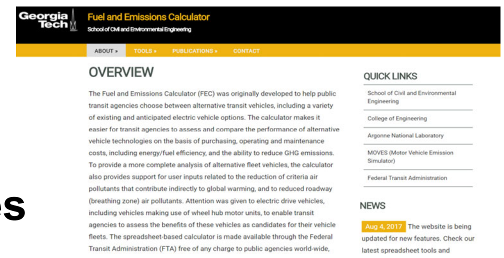
MOVES-Matrix 2.0

- ➢ MOVES-Matrix for regional inventory modeling
  - ➢ Start exhaust, truck hoteling, and evaporative emissions
- ➢ Atlanta regional inventory case study
- ➢ MOVES-Matrix generates exactly the same results
- ➢ Provides tremendous flexibility for use in scenario analysis

Xu, X., H. Liu, H. Li, M.O. Rodgers, R. Guensler (2018). "Integrating Engine Start, Soak, Evaporative, and Truck Hoteling Emissions into MOVES-Matrix. "Transportation Research Record. Washington, DC. 2018.

Fuel and Emissions Calculator (FEC) http://fec.ce.gatech.edu/

- Originally for transit to help agencies assess and compare alternative transit vehicle technologies
  - Capital costs
  - Operating/maintenance costs
  - Energy use and emissions
  - Includes hybrids and EVs
- Now applies to most vehicle classes
- Lifecycle analysis
  - On-road pump-to-wheel (PTW) from MOVES-Matrix
  - Upstream well-to-pump (WTP) from GREET



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MOVES-Matrix Applications

- MOVES-Matrix can be applied at any spatial and temporal scale and can be linked with any model via Python scripts
  - Regional travel demand models
  - Corridor/scenario analysis
  - Vissim™ and other microscopic simulation models
  - Microscale pollutant dispersion modeling
  - App-based vehicle energy and emissions modeling
- The FEC and Cost Calculator can be applied in series

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MOVES-Matrix 2.0
Travel Demand Model Connectivity

- MOVES-Matrix 2.0
- Atlanta Regional Commission’s (ARC’s) regional activity-based travel demand model
- Activity-based model (ABM) predicts trips (origin-destination) and link-level travel
  - 5,873 zones
  - 74,469 network links

Source: Atlanta Regional Commission

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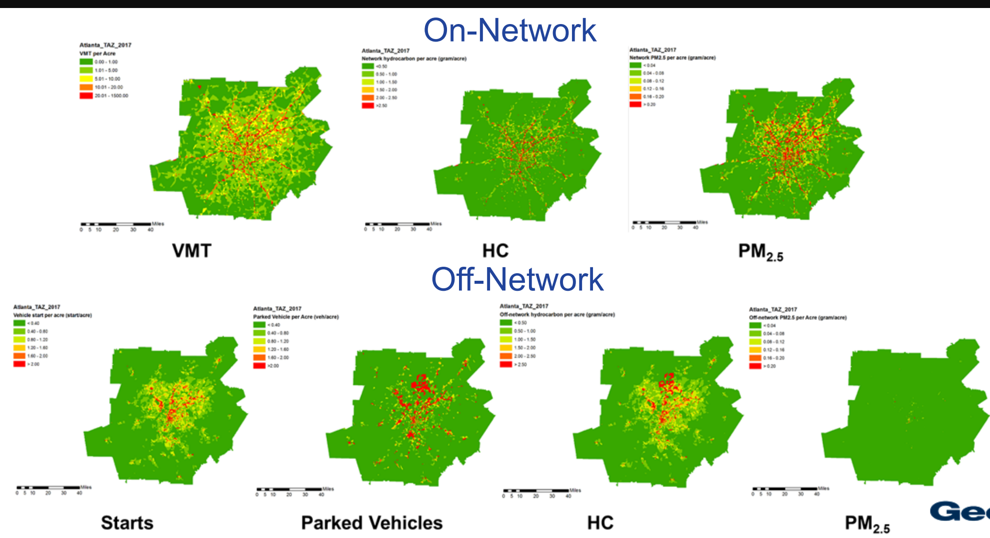
Atlanta’s Activity-Based Model (ABM)
On-network and Off-network Emissions



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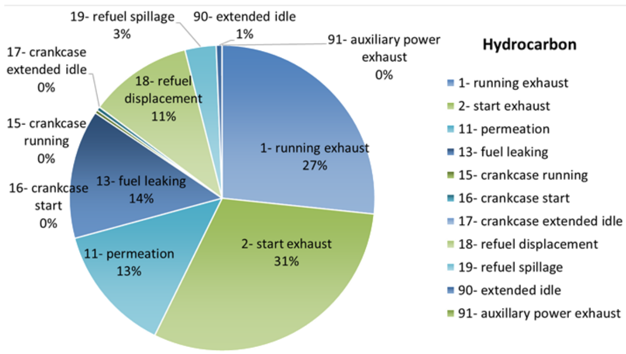
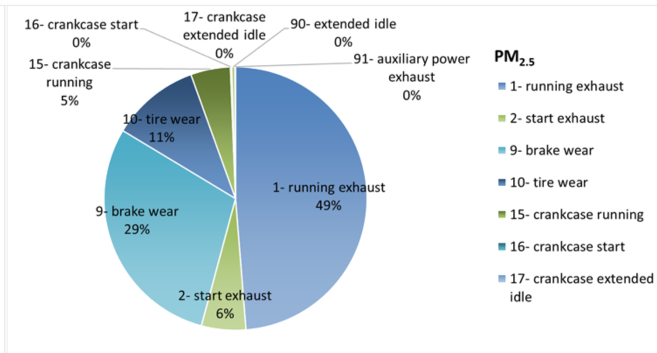
Activity-Based Model (ABM) Inventory by Emissions Source





Xu, X., H. Liu, Y. Xu, M. Rodgers and R. Guensler (2018). Regional Emission Analysis with Travel Demand Models and MOVES-Matrix (18-05363). 97th Annual Meeting of the Transportation Research Board (presentation only, full paper review, extended abstract in proceedings). Washington, DC. January 2018.

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Vissim™ Microscopic Simulation

- Automated linkage between Vissim™ and MOVES-Matrix
- Python scripts
  - Run Vissim™ microscopic simulation (defined network)
  - Retrieve vehicle trace data via Vissim™ COM interface
  - Assign source types
  - Process sec-by-sec trace data to VSP
  - Match to MOVES-Matrix energy/emission rates
  - Append energy/emissions to trace data

Xu, X., H. Liu, Y. Xu, M. Hunter, and R. Guensler (2016). "Estimating Project-level Vehicle Emissions using Vissim™ and MOVES Matrix." DOI 10.3141/2570-12. Transportation Research Record. Number 2570. pp. 107-117. National Academy of Sciences. Washington, DC. 2016.

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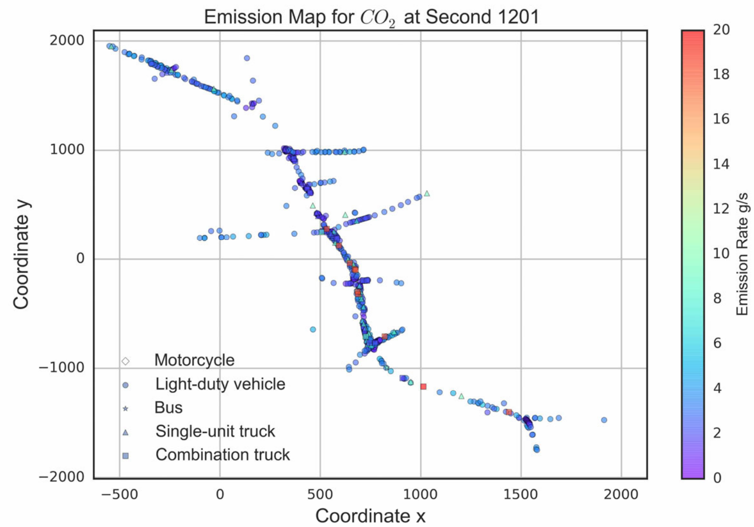
Vissim™ and MOVES-Matrix (Animation) Jimmy Carter Boulevard, Gwinnett, GA



Includes 12 signalized intersections and freeway ramps

With links to microscale dispersion models

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AERMOD Pollutant Dispersion Analysis

- **Air quality impact assessment screening**
- **Microscale pollutant concentrations at the regional scale**
  - **MOVES-Matrix for emission rates**
  - **AERMOD for microscale dispersion**
- **Outputs "worst case" pollutant concentrations**
  - **Identify insignificant impacts**
  - **Identify potential hot-spots (for deeper investigation)**

Liu, H., D. Kim, H. Lu, R. Wayson, M.O. Rodgers, and R. Guensler (2019). A Regional Air Quality Impact Assessment Screening Tool based upon MOVES-Matrix and AERMOD. Guidelines on Air Quality Models: Planning Ahead. AWMA 8th Specialty Conference on Air Quality Modeling. Durham, NC. March 19-21, 2019.

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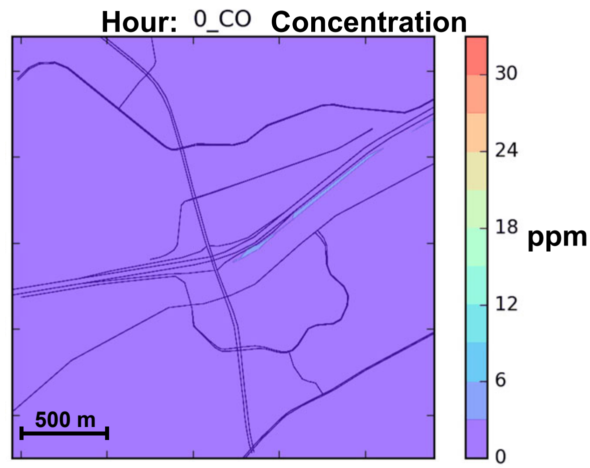
AERMOD Dispersion Modeling (Animation) Jimmy Carter Boulevard, Gwinnett, GA

- Hourly CO concentrations
  I-85 and Jimmy Carter Blvd.
- Winter weekday 2012
- Background excluded

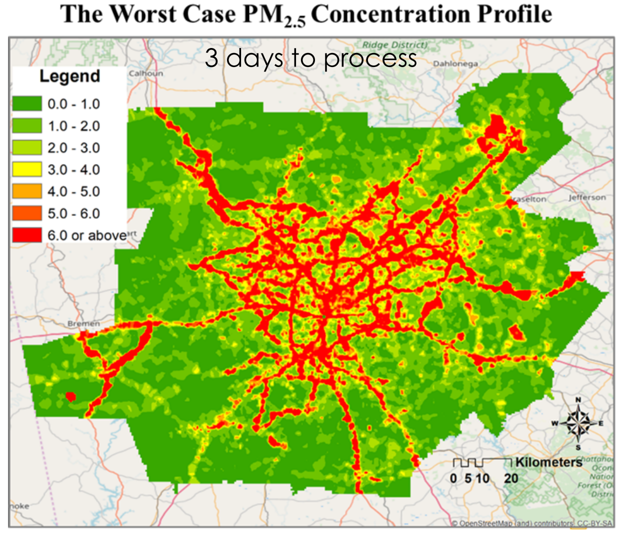


Liu, H., X. Xu, M.O. Rodgers, Y. Xu, and R. Guensler (2017) MOVES-Matrix and Distributed Computing for Microscale Line Source Dispersion Analysis. Journal of the Air & Waste Management Assoc. 67(7):763-775.

Region-scale AERMOD Dispersion Modeling Case Study for $PM_{2.5}$

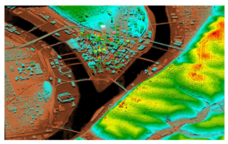
- Atlanta Metropolitan Area
- The worst-case and standard modeling
- 19,016 roadway miles
- 161,188 polygon segments
- 1,163,958 receptors
- 10-day process on PACE
  - 3-days for worst case

The Worst Case $PM_{2.5}$ Concentration Profile



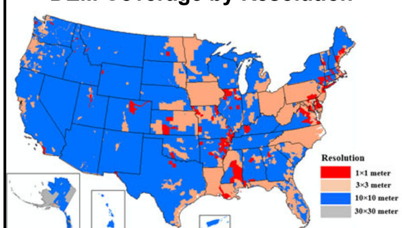
Kim, D., H. Liu, X. Xu, H. Lu., R. Wayson, M.O. Rodgers, R. Guensler. (2019) Streamlined Data Processing for Regional Scale Applications of Line Source Dispersion Modeling via Distributed Computing. 99th Transportation Research Board (TRB) Annual Meeting.

Road Grade Development using the U.S. Geological Survey Digital Elevation Model



USGS DEM Cloud Point for Pittsburgh, PA
Source: http://nationalmap.gov/elevation.html

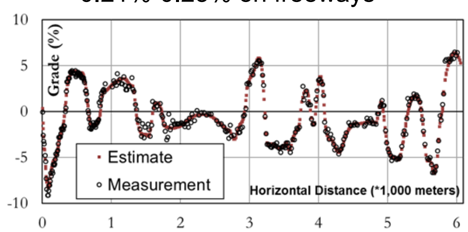
DEM Coverage by Resolution



Distance-Grade Profile (Measurement vs. Estimation)

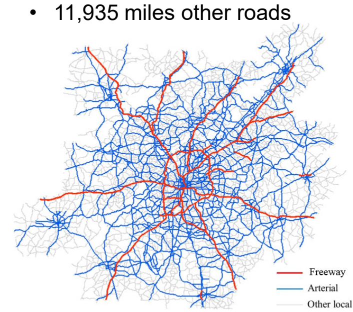
RMSE:

- 0.5-0.58% on arterials
- 0.21%-0.23% on freeways



Road Grade Map for Atlanta

- 1,435 miles of freeways
- 7,493 miles of major arterials
- 11,935 miles other roads



Liu, H., H. Li, M.O. Rodgers, and R. Guensler (2018). Development of Road Grade Data Using the United States Geological Survey Digital Elevation Model. *Transportation Research Part C: Emerging Technologies*, 92, pp. 243-257.

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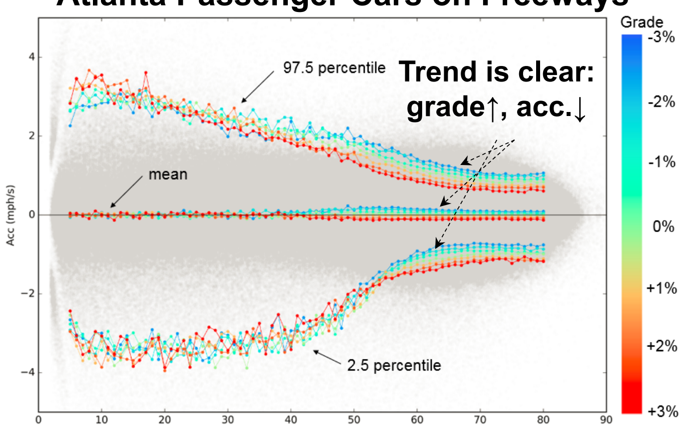
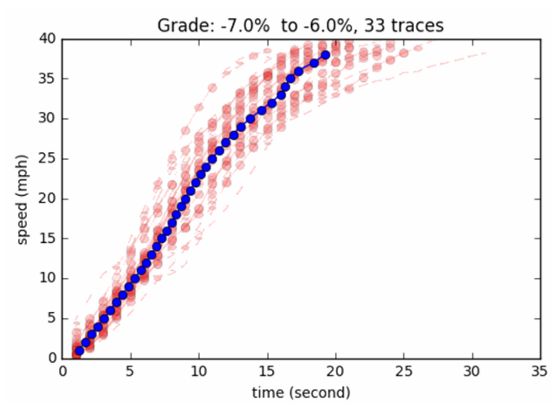
Road Grade Impact on On-road Operations

Extreme and Mean Acceleration by Grade Atlanta Passenger Cars on Freeways



MARTA Acceleration Traces (0-40 mph) on Grades



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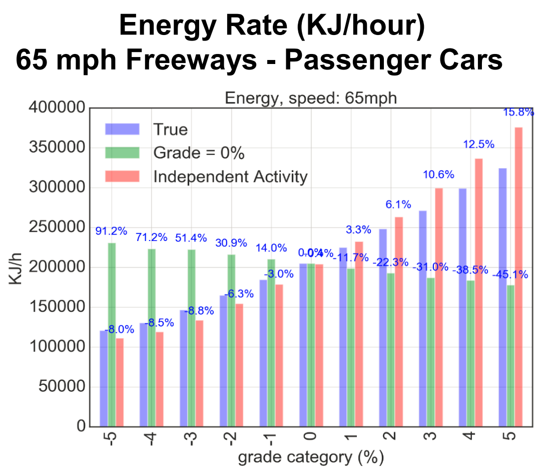
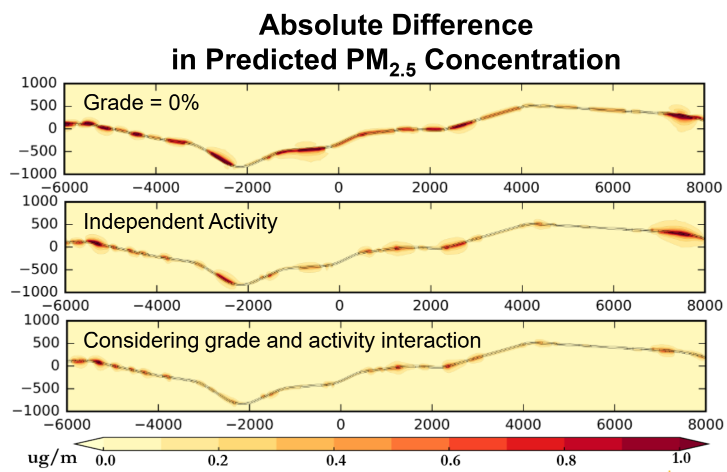
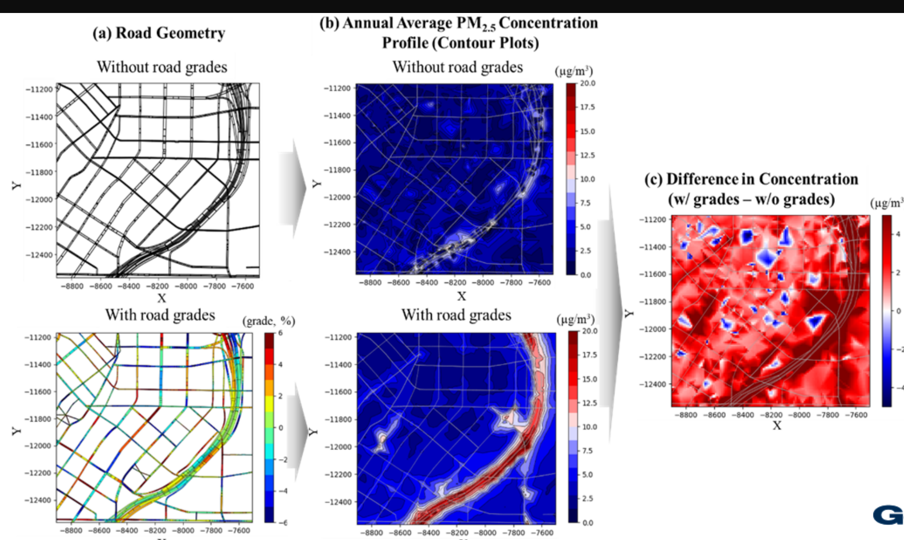
Impact of Road Grade on Energy and Air Quality Modeling



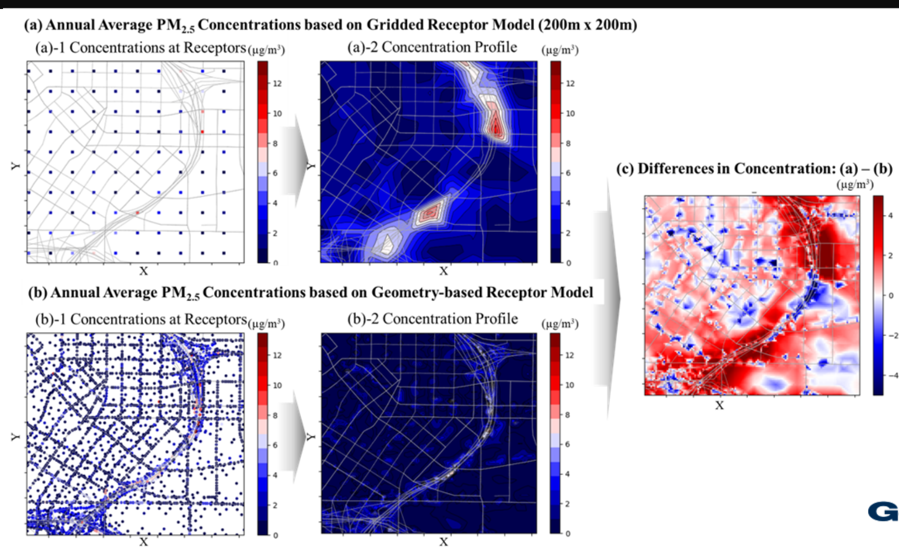


Liu, H. (2018). Modeling The Impact of Road Grade on Vehicle Operation, Vehicle Energy Consumption, and Emissions. Dissertation. Georgia Institute of Technology, School of Civil and Environmental Engineering. Atlanta, GA.

Integration of Road Grade Profiles



Receptors at High Spatial Resolution



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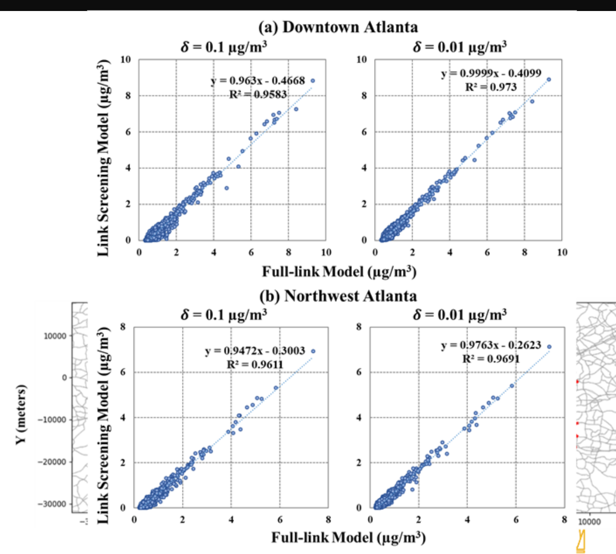
Supervised Link Screening (SLS)

- SLS eliminates links that do not contribute significantly to predicted receptor concentrations
- AERMOD run-times were reduced by 98.9%-99.8%
- SLS explained 95%-97% of concentration, compared to all-link models



Ongoing Modeling Work

- New dissertations and theses:
  - Autonomie-based, simulation-informed, VSP modeling of hybrid/electric vehicles
  - Transit fleet EV optimization models
- Forthcoming:
  - Distributive justice assessment tools for planning
  - Pollutant exposure assessment tools for health effects

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Simulation-Informed Energy Modeling for LDV Hybrids and BEVs (VSP Binning)

- MOVES currently excludes BEVs, HEVs, PHEVs, and FCEVs
- Develop MOVES-compatible models that achieve comparable results to full-vehicle simulation models (e.g., Autonomie)
  - Predict modal energy use for on-road operating conditions
  - Ensure energy use prediction scalability for individual vehicles, corridors, and regional energy use
  - Reasonable accuracy

PRIUS

TESLA

MIRAI FUEL CELL

Xu, X. (2019). Next Generation Electric Vehicle Energy Modeling In Transportation Networks. Dissertation. Georgia Institute of Technology, School of Civil and Environmental Engineering. Atlanta, GA.

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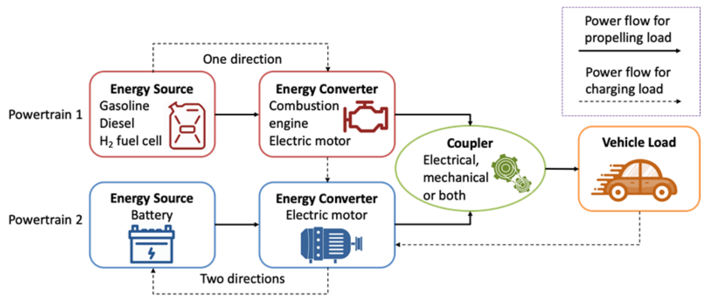
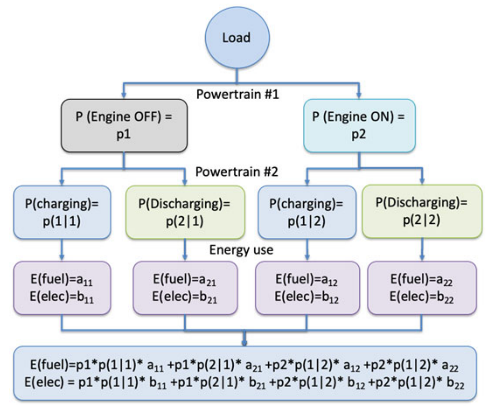
Simulation-Informed Energy Modeling for LDV Hybrids and BEVs (with VSP Binning)

Conceptual Framework



Source: Ehsani, et al., 2018

Bayesian Modeling

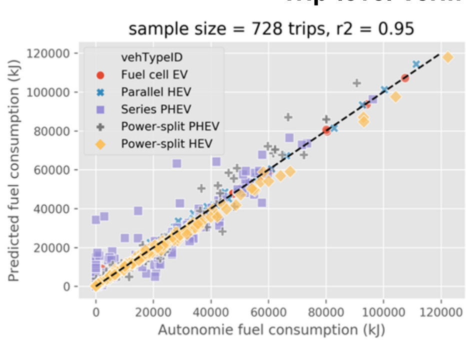


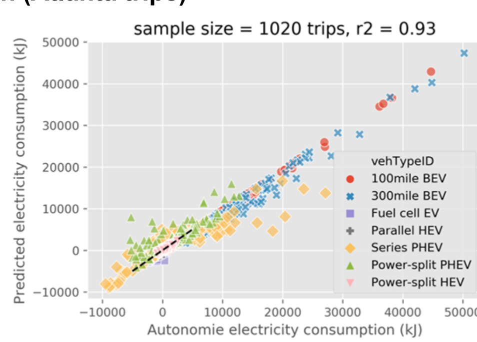
Xu, X. (2019). Next Generation Electric Vehicle Energy Modeling In Transportation Networks. Dissertation. Georgia Institute of Technology, School of Civil and Environmental Engineering. Atlanta, GA.

Simulation-Informed Energy Modeling for LDV Hybrids and BEVs (with VSP Binning)

Bayesian Network Energy Model Performance

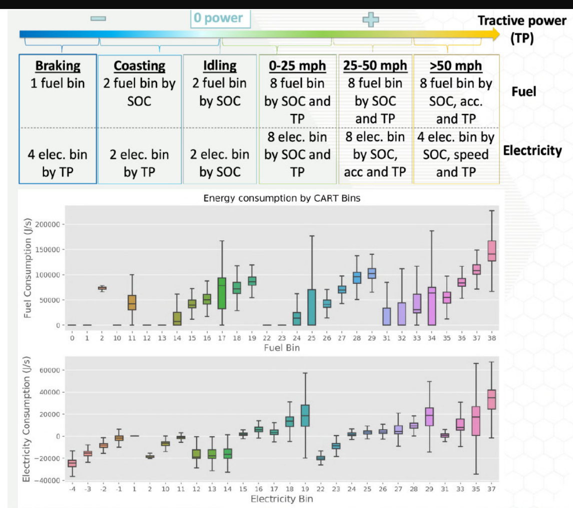
Trip-level Verification (Atlanta trips)



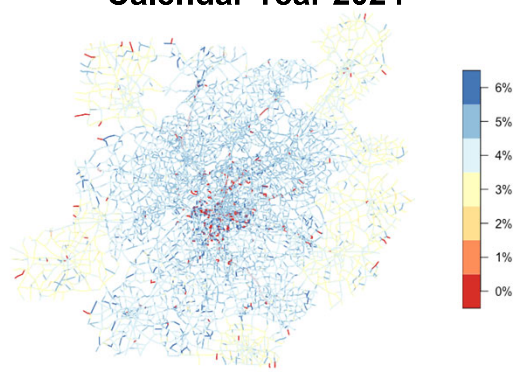


Xu, X. (2019). Next Generation Electric Vehicle Energy Modeling In Transportation Networks. Dissertation. Georgia Institute of Technology, School of Civil and Environmental Engineering. Atlanta, GA.

Scalable Applications of the Energy Model for LDV Hybrids and BEVs



Annual Percent Fuel Savings by Link
Metro Atlanta 20-County Network
Calendar Year 2024



Xu, X. (2019). Next Generation Electric Vehicle Energy Modeling In Transportation Networks. Dissertation. Georgia Institute of Technology, School of Civil and Environmental Engineering. Atlanta, GA.

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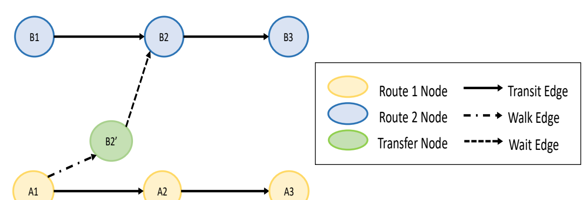
RoadwaySim (Regional Roadway Simulator) TransitSim (Regional Transit Simulator)

- **Python-based shortest-path models**
  - **203,000-link road network**
  - **90+ MARTA bus/rail routes**
  - **23 GRTA Xpress Bus routes**



- **Users input origin-destination pair and departure time**
- **Simulators find shortest path trajectories through space and time**

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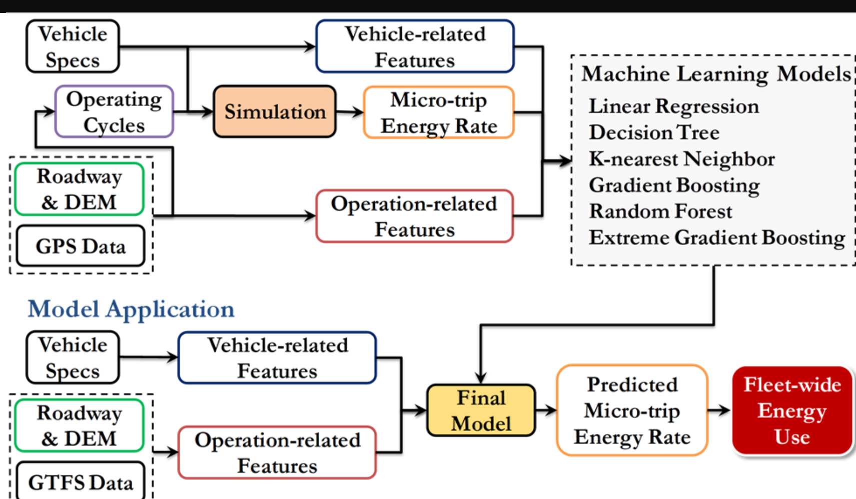
Framework for Assessing Transit Fleet Energy Consumption with Alternative Fuels

- Models predict transit vehicle energy use for micro-trips
- Simplified versions of full-vehicle simulations
  - Comparable results (R^2 close to 1 and MAPE <3%)
- Agencies can assess transit vehicle performance for an array of alternative fuel vehicles and future fleets on specific routes and specified on-road operating conditions
- Users can optimize vehicle-route assignment and fleet procurement decisions over time (e.g., electric buses)
- Applied to MARTA service in Atlanta, Georgia

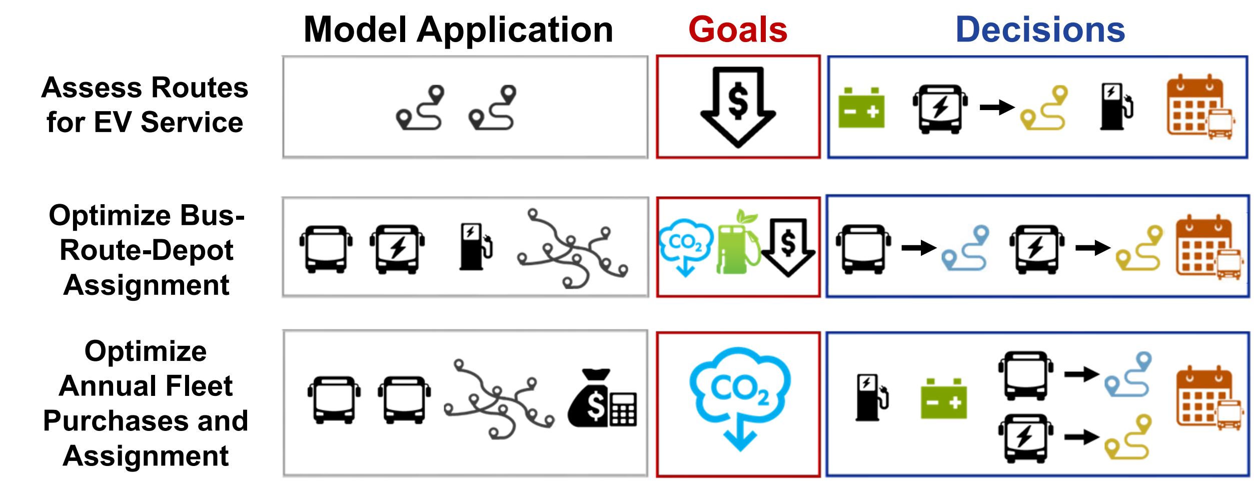
Li, H. (2019). A Framework for Optimizing Public Transit Bus Fleet Conversion to Alternative Fuels. Dissertation. Georgia Institute of Technology, School of Civil and Environmental Engineering. Atlanta, GA.

Transit Energy Model Development



Li, H. (2019). A Framework for Optimizing Public Transit Bus Fleet Conversion to Alternative Fuels. Dissertation. Georgia Institute of Technology, School of Civil and Environmental Engineering. Atlanta, GA.

Transit Optimizer Model Applications



Li, H. (2019). A Framework for Optimizing Public Transit Bus Fleet Conversion to Alternative Fuels. Dissertation. Georgia Institute of Technology, School of Civil and Environmental Engineering. Atlanta, GA.

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Summary

- MOVES-Matrix (brute-force MOVES modeling)
  - Obtains exactly the same energy and emissions rates
- Can be applied at any spatial and temporal scale
  - Regional, corridor case studies, simulations, apps, etc.
  - Scripts link with traditional regional and simulation models
  - Can link with dispersion models (e.g., AERMOD-Grid)
- Matrices are very large
  - Python scripts are required
  - Distributed computing, GIS, and visualization expertise helps
- Connections with new energy optimization models and deep learning applications are evolving

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