Integrating Models at Multiple Scales for Transportation Energy and Emissions Assessment

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USEPA MOVES Review Workgroup
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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)

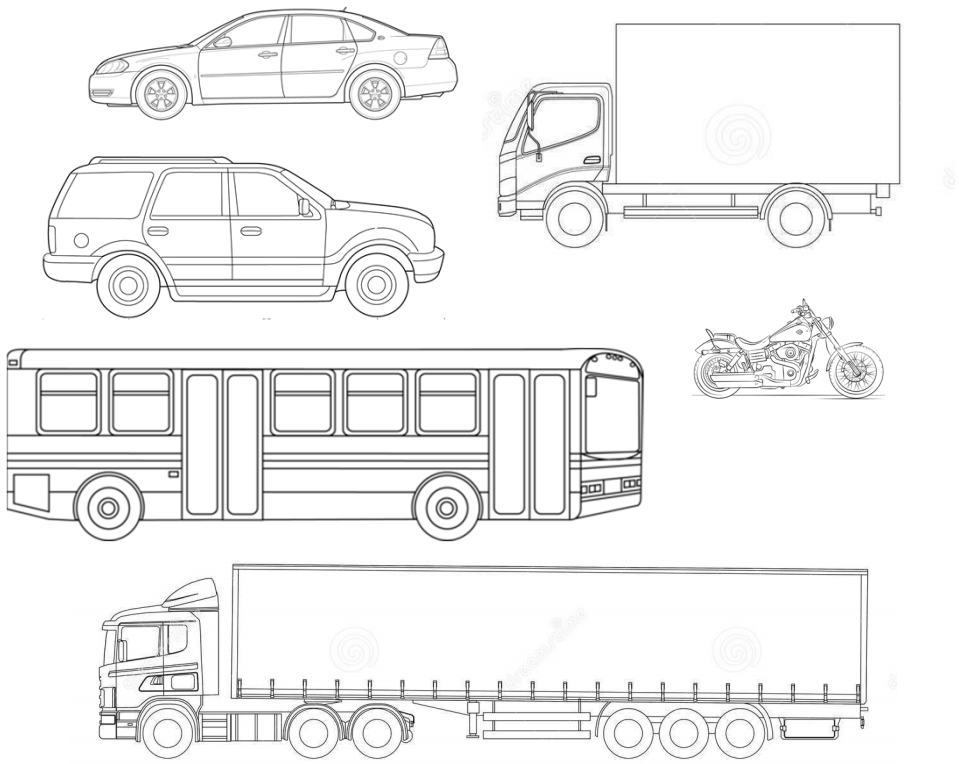
MOVES Modeling

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

- 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

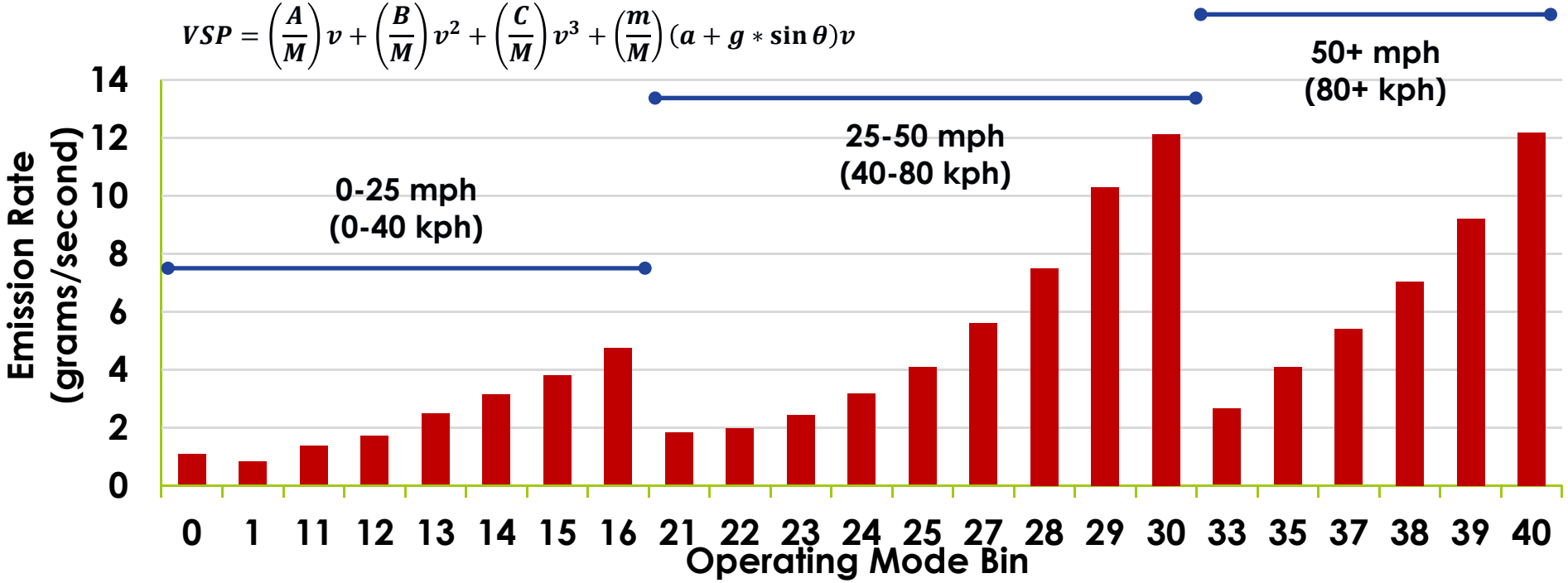
13 MOVES Source Types

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 VSP Bin for Passenger Trucks (2016MY in 2016)

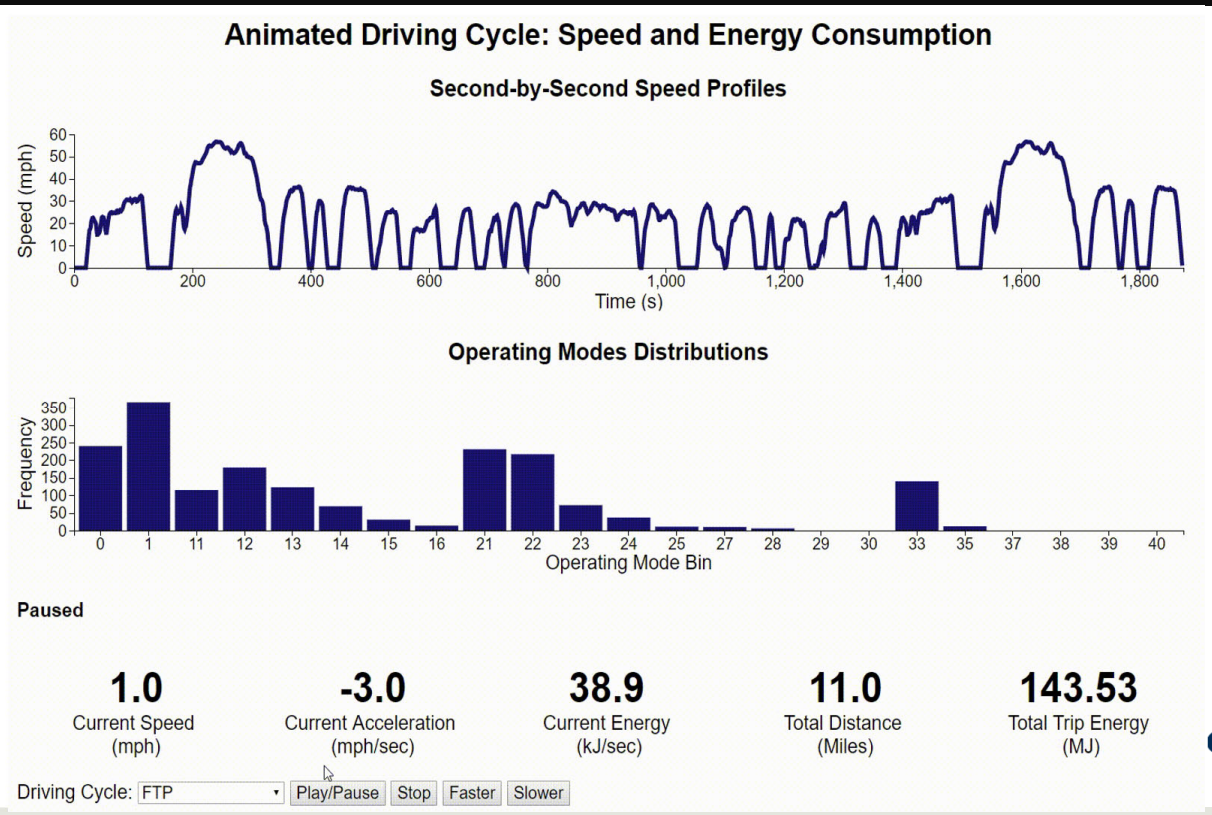
$$VSP = \left(\frac{A}{M}\right)v + \left(\frac{B}{M}\right)v^2 + \left(\frac{C}{M}\right)v^3 + \left(\frac{m}{M}\right)(a + g * \sin\theta)v$$



23 operating mode bins

0 = braking, 1 = idle, 11 = coast, 21 = coast

FTP Driving Cycle



Traditional MOVES Modeling

- Modeling of complicated and dynamic networks is tedious
  - Requires generation of many link emission rates
  - Users often generate 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

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
- 1.2 millions of MOVES runs to date

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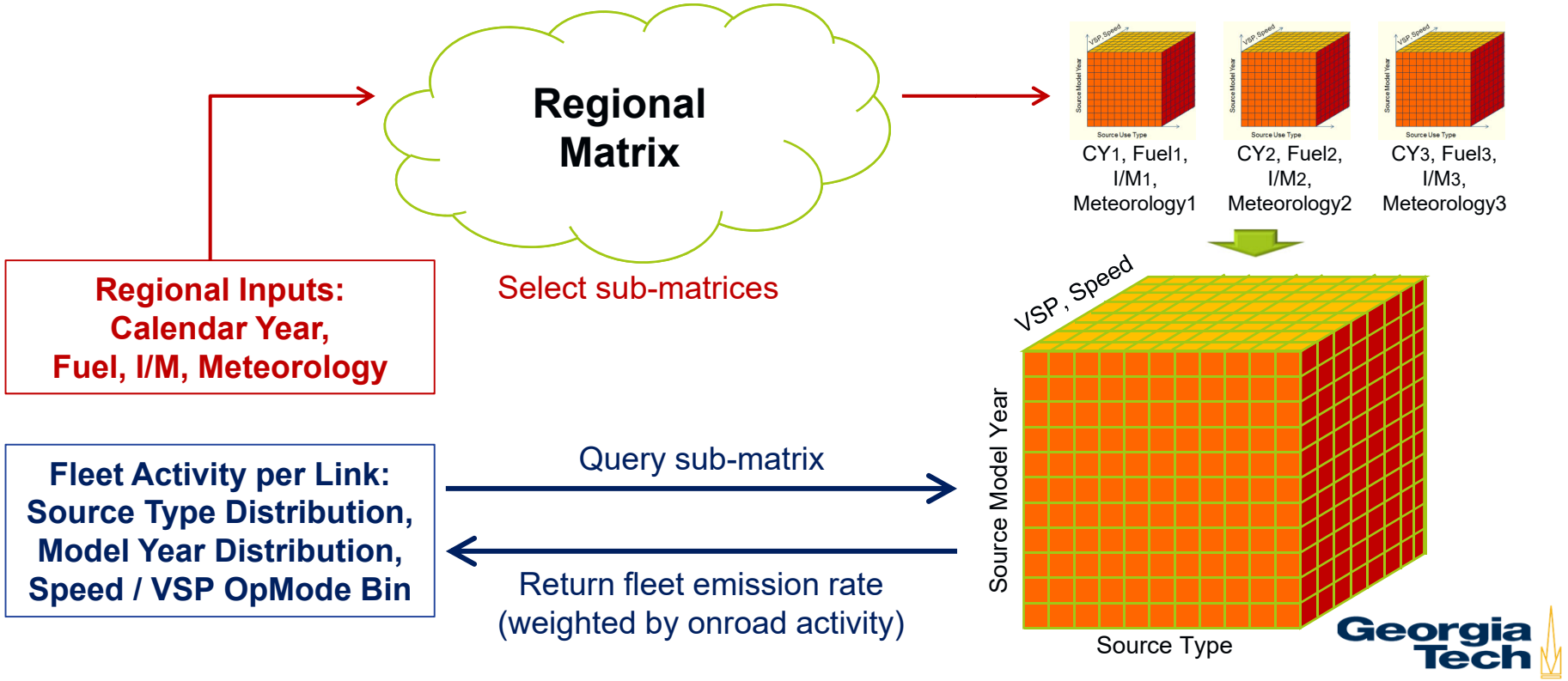
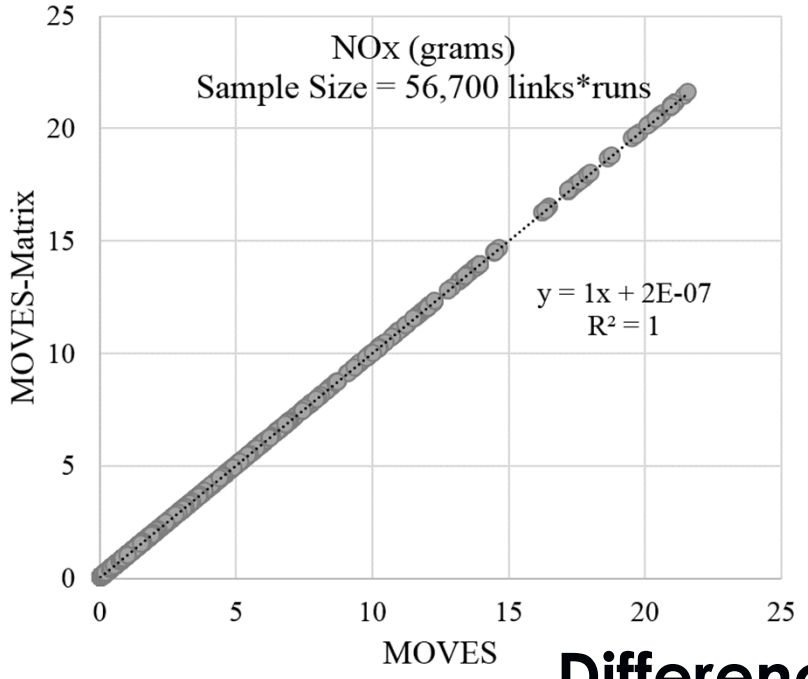
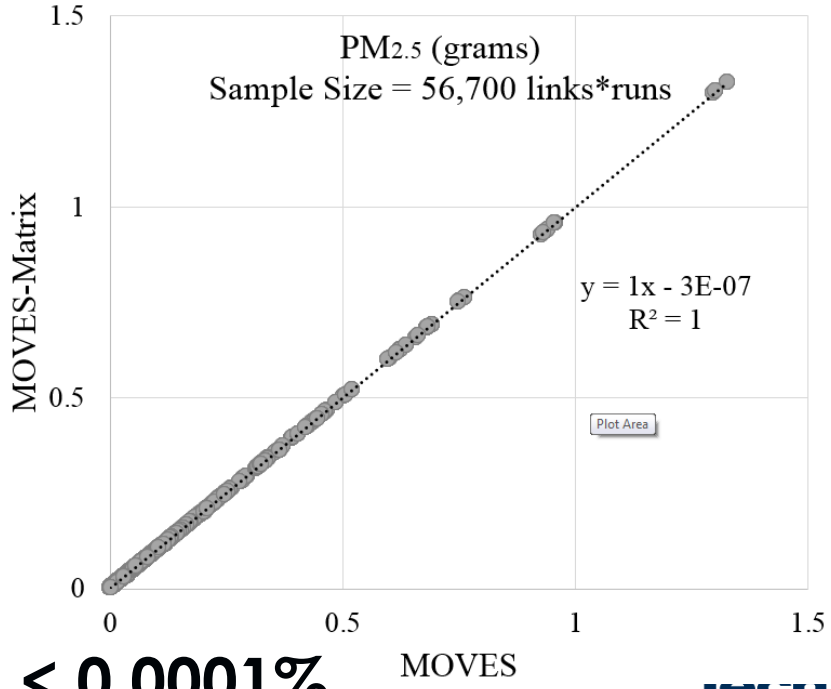
MOVES-Matrix Run Module: Developing On-Road Fleet Emission Rates



MOVES vs. MOVES-Matrix Results

- **Results are exactly the same as MOVES GUI results**





Difference < 0.0001%

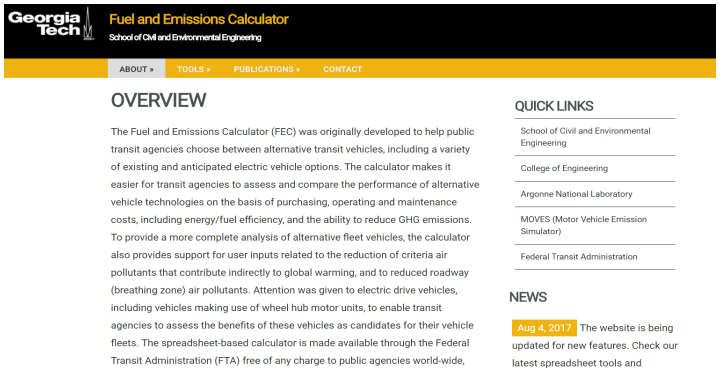
MOVES-Matrix 2.0

- 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 transit-only, to help agencies assess and compare alternative transit vehicle technologies
  - Capital costs
  - Operating/maintenance costs
  - Energy use and emissions
  - Includes hybrids and EVs



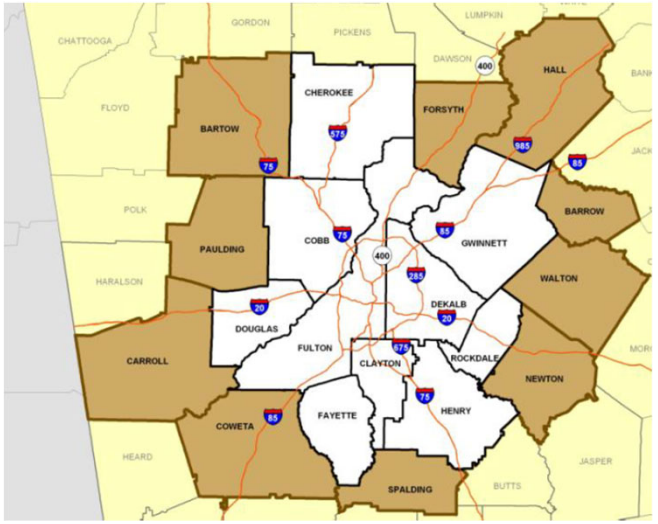
- Lifecycle analysis
  - On-road pump-to-wheel (PTW) from MOVES-Matrix
  - Upstream well-to-pump (WTP) from GREET

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

MOVES-Matrix 2.0
Travel Demand Model Connectivity

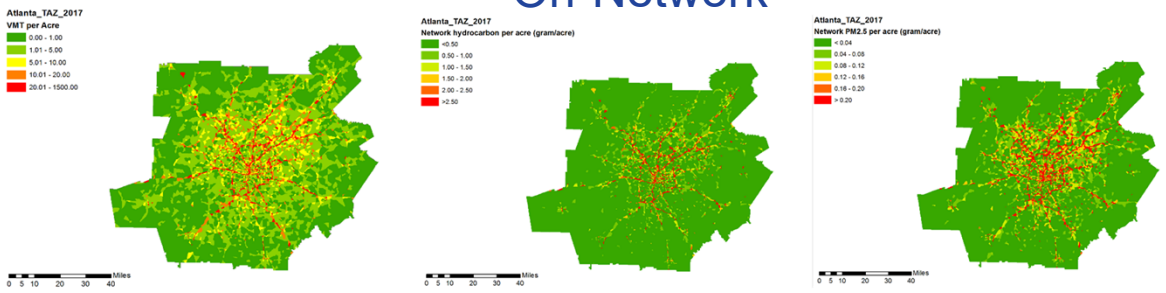
- **MOVES-Matrix 2.0**
- **Atlanta Regional Commission's (ARC's) regional activity-based travel demand model ABM**
- **Activity-based model (ABM) predicts trips (origin-destination) and link-level travel**
  - **5,873 zones**
  - **74,469 network links**



Source: Atlanta Regional Commission

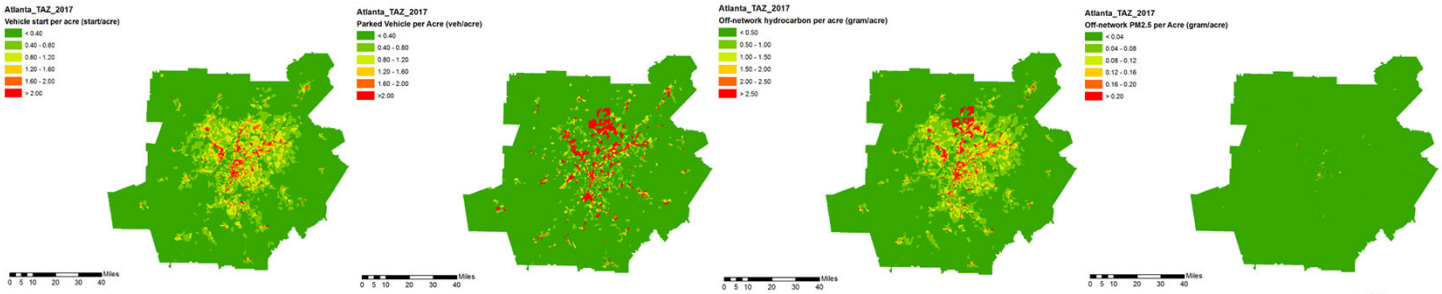
Atlanta's Activity-Based Model (ABM) On-network and Off-network Emissions

On-Network



VMT HC $PM_{2.5}$

Off-Network



Starts Parked Vehicles HC $PM_{2.5}$

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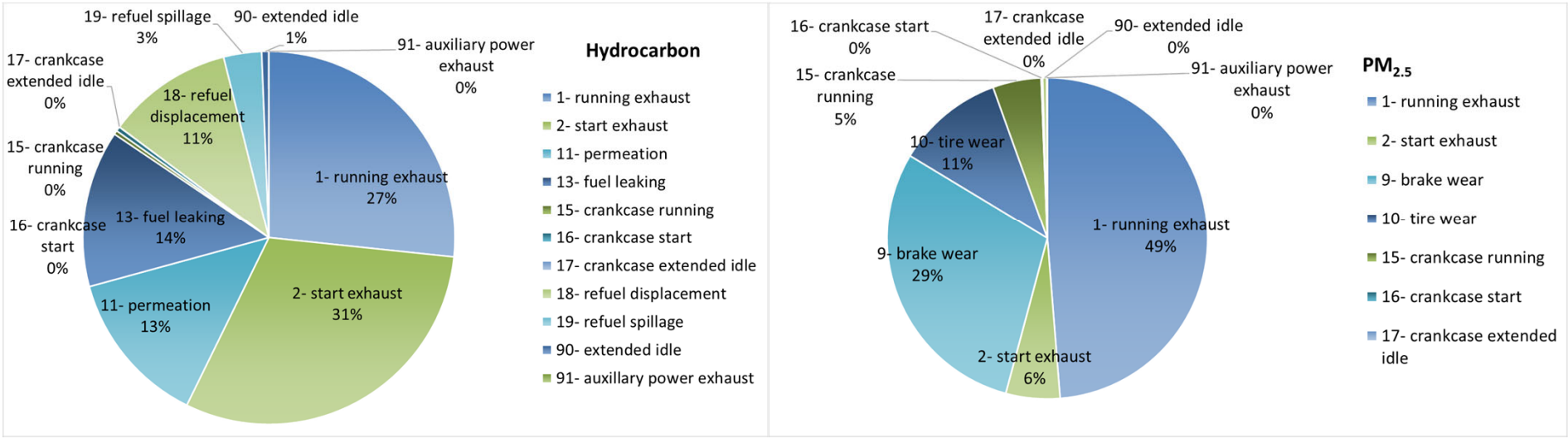
ABM Activity-Based Model Inventory by Emissions Source



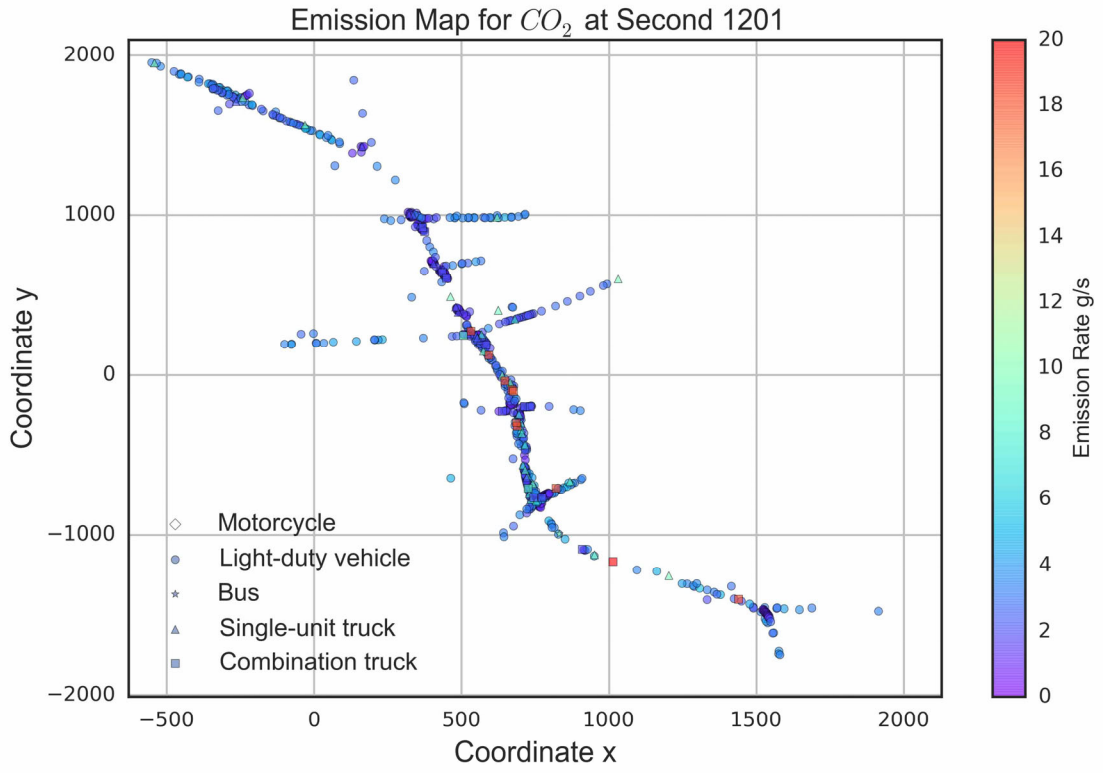
Xu, X., H. Liu, Y. Xu, M. Rodgers and R. Guensler (2018). Regional Emission Analysis with Travel Demand Models and MOVES-Matrix (18-05363). 97th Annual Meeting of the Transportation Research Board (presentation only, full paper review, extended abstract in proceedings). Washington, DC. January 2018.

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.

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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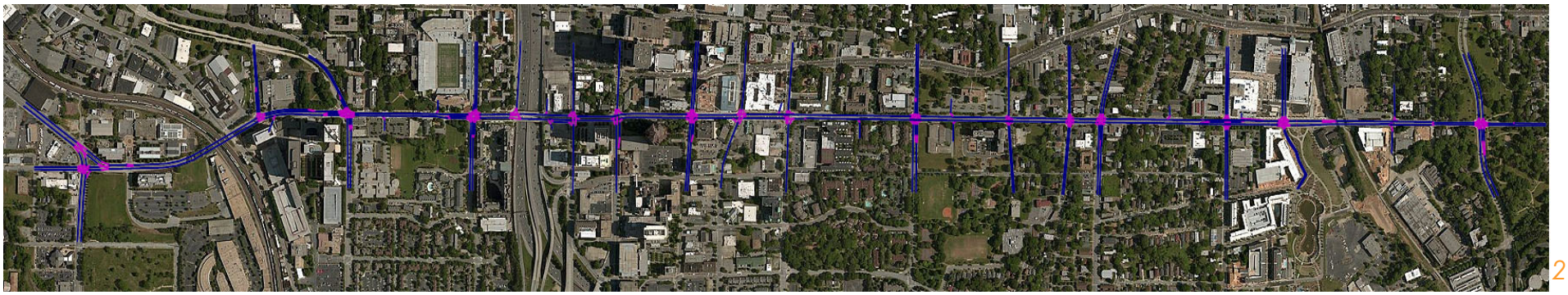
Atlanta's North Avenue Smart Cities Real-time Corridor Simulation

- **Assess the benefits of using real-time data-driven simulation with dynamic traffic control**



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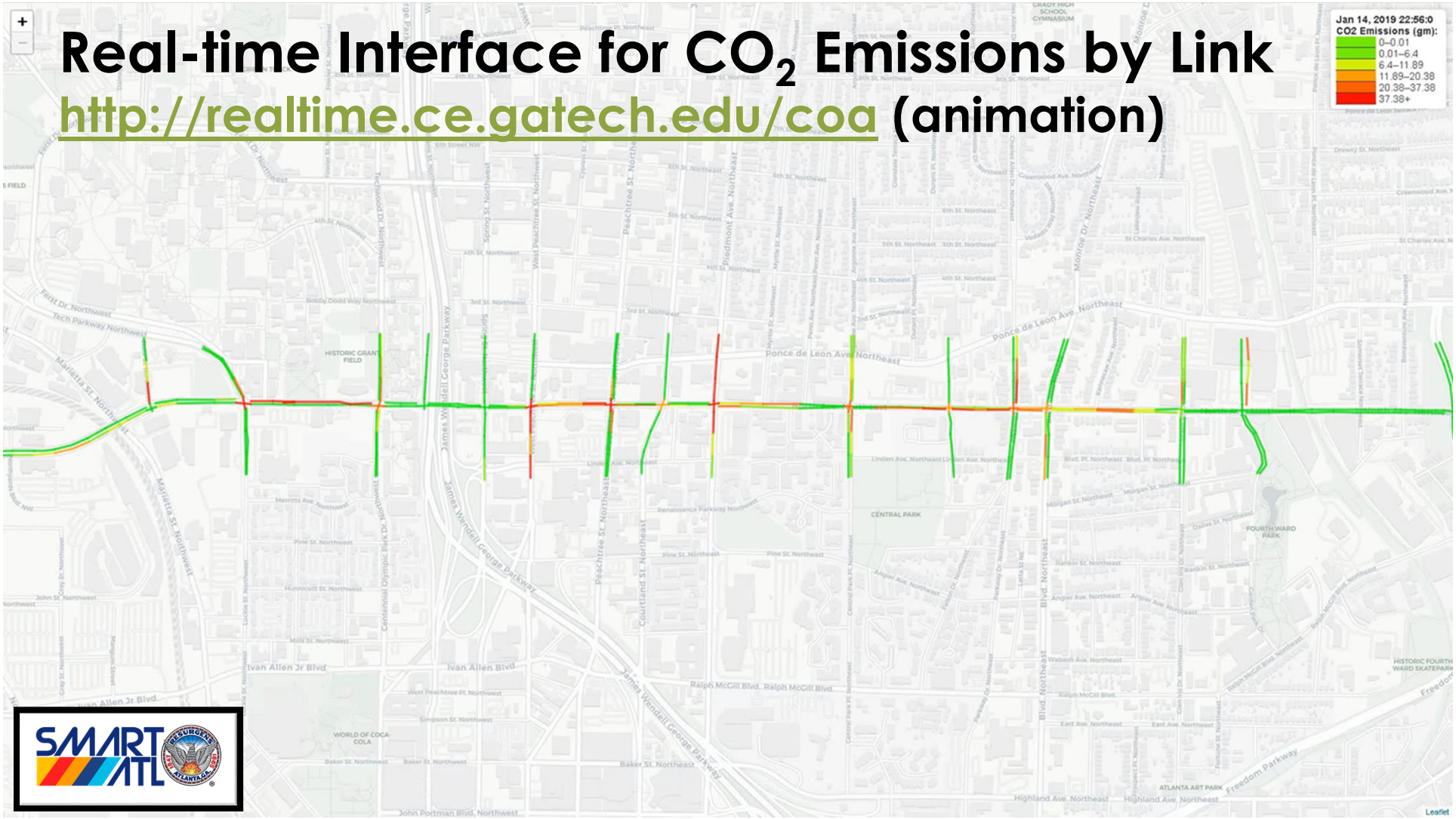
North Avenue Corridor Vissim™ Simulation Model

Real-world case study employs monitored and modeled data

Improve the quality of life for City of Atlanta stakeholders (residents, employers, employees, and visitors)

Real-time Interface for CO_2 Emissions by Link

http://realtime.ce.gatech.edu/coa (animation)



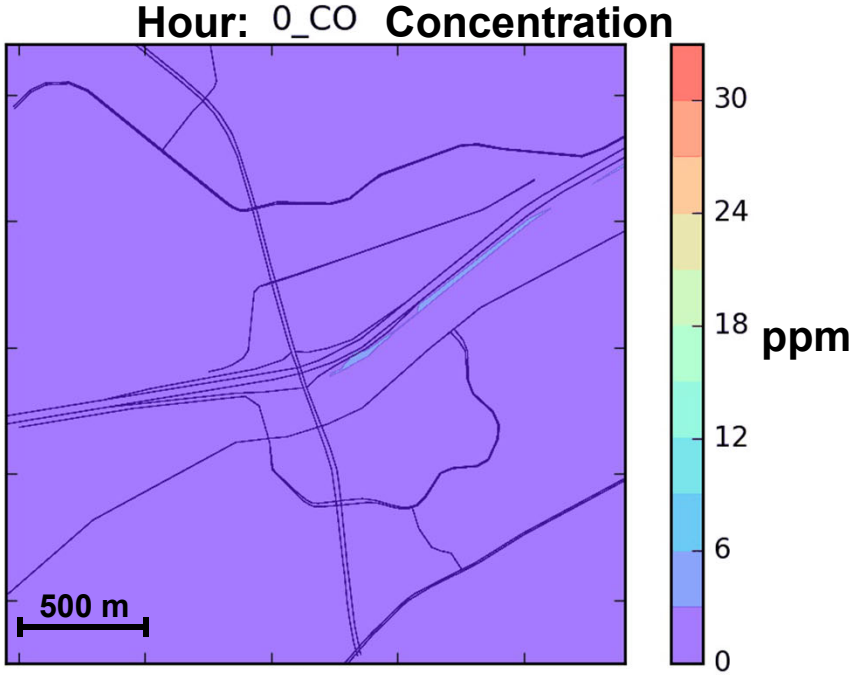
AERMOD
Pollutant Dispersion Analysis

- 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.

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

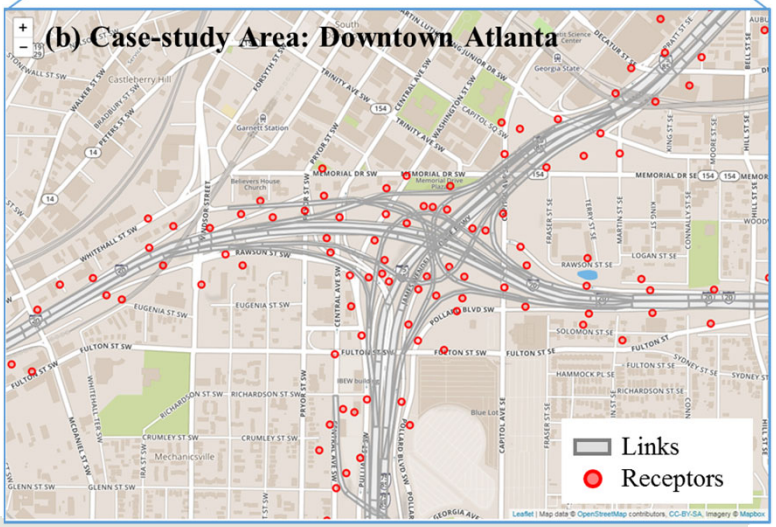
- **Hourly CO concentrations**
  I-85 and Jimmy Carter Blvd.
- **Winter weekday 2012**
- **Background excluded**



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.

AERMOD-Grid Case Study for $PM_{2.5}$

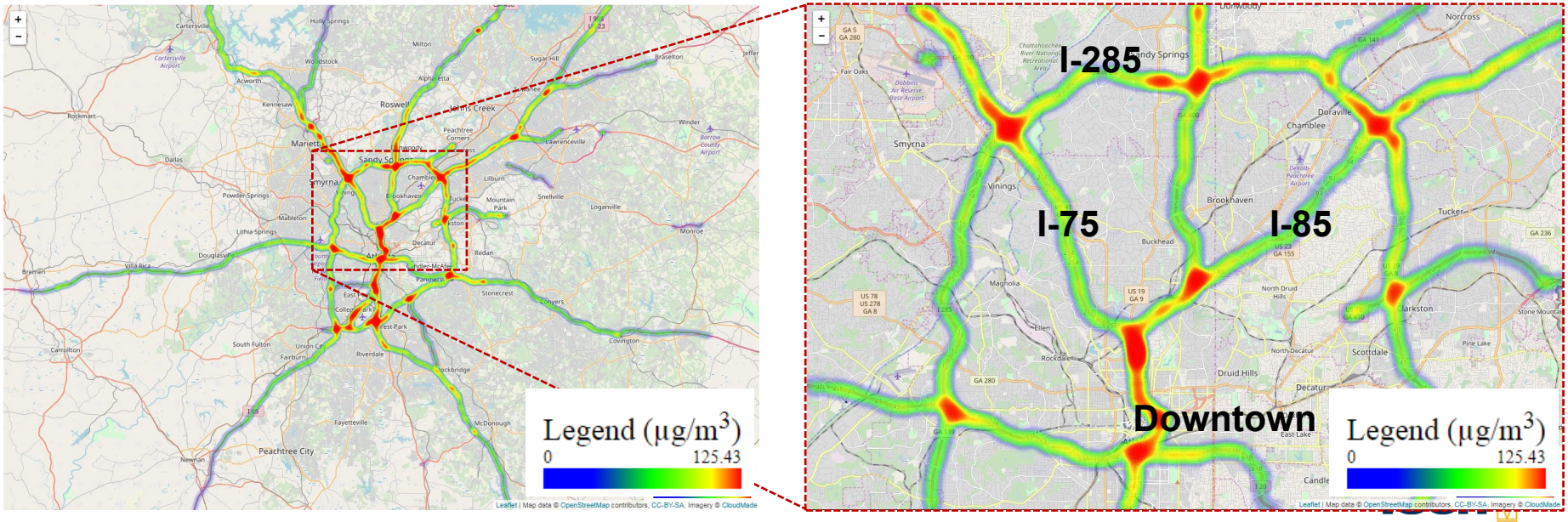
- Atlanta Metropolitan Area
- All highways (I-85, I-75, I-20, etc.)
- 1,163 roadway miles
  - 976 highway miles
  - 189 ramp miles
- 5,642 polygon link segments
- 54,017 receptors
- 7-day PACE modeling run



Results can be found at:
http://movessensitivity.ce.gatech.edu/osm_link_emissions/outputs.html

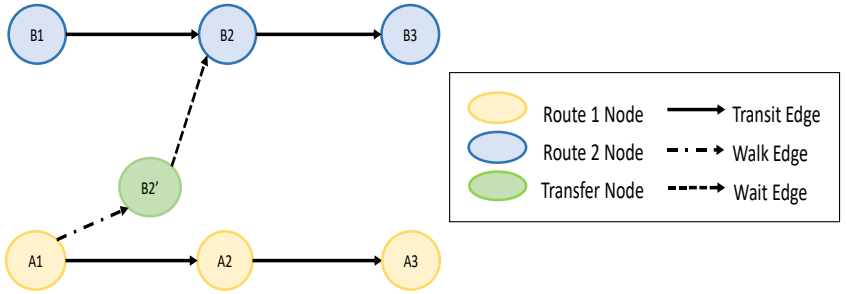
$PM_{2.5}$ Emissions and Dispersion Modeling (Atlanta Regional Case Study)

- Atlanta freeway worst case AERMOD assessment
- Identifies areas for more refined modeling



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

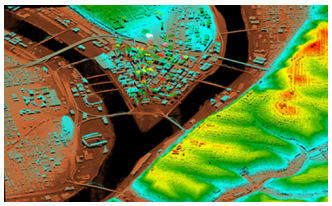


- Users input origin-destination pair and departure time
- Simulators find shortest path trajectories through the STM
  - Trajectories move through space and time
  - Accounts for congestion formation and dissipation

Ongoing Work

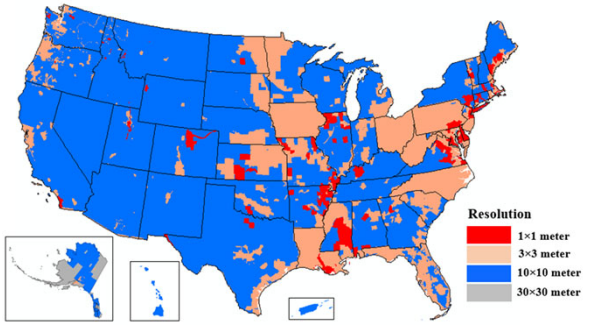
- New dissertations and theses:
  - Road grade integration into the modeling tools
  - Autonomie-based, simulation-informed, VSP modeling of hybrid/electric vehicles
  - Transit fleet EV integration optimization model
- Forthcoming:
  - Distributive justice assessment tools for planning
  - Pollutant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

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

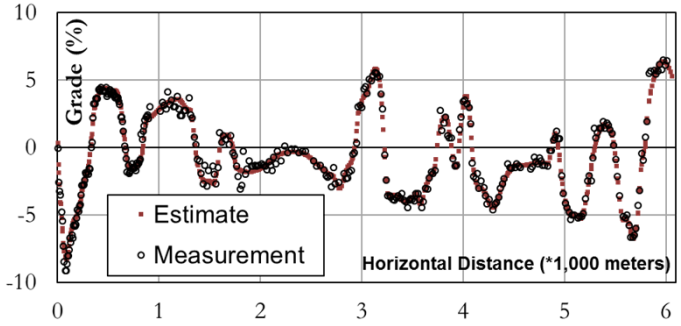
DEM Coverage by Resolution



Distance-Grade Profile (Measurement vs. Estimation)

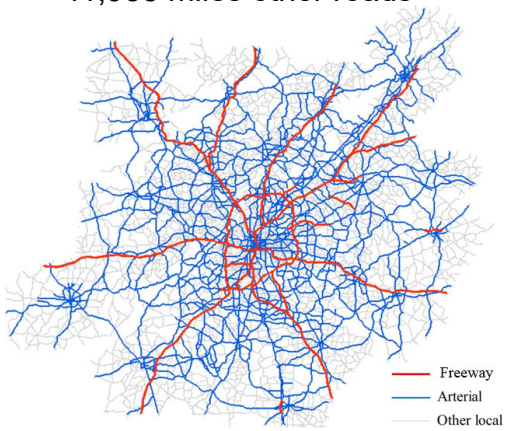
RMSE:

- 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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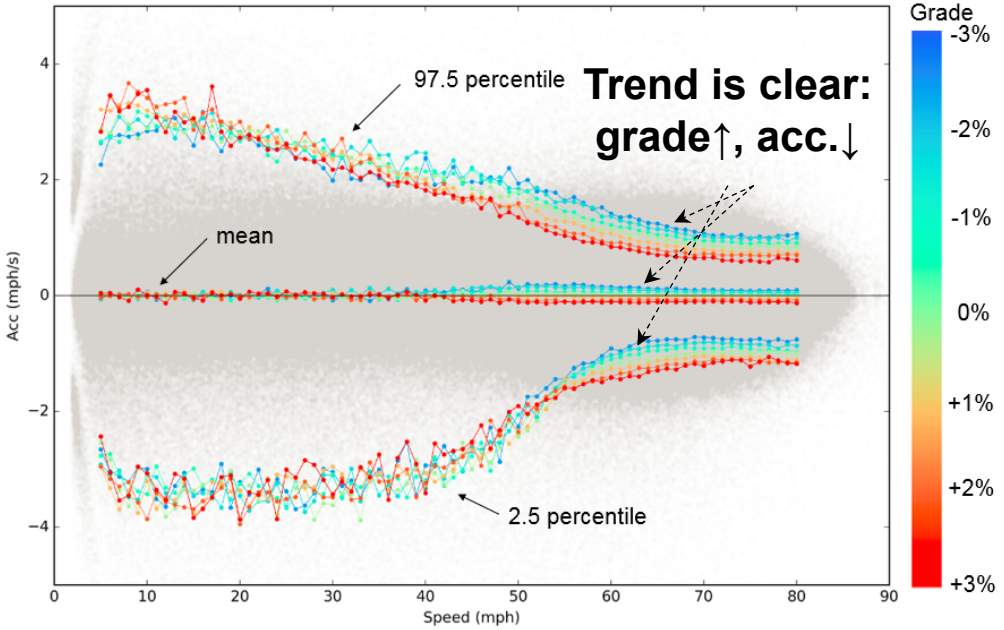
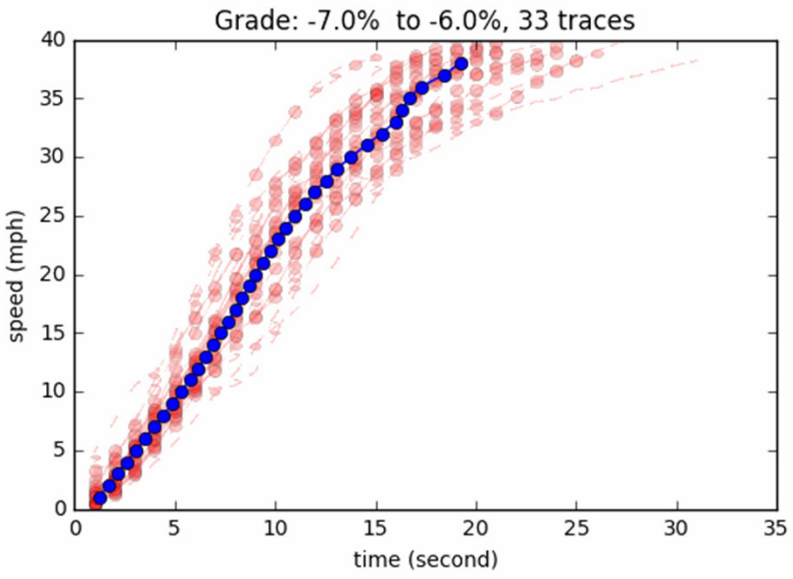
Road Grade Impact on On-road Operations

Extreme and Mean Acceleration by Grade Atlanta Passenger Cars on Freeways

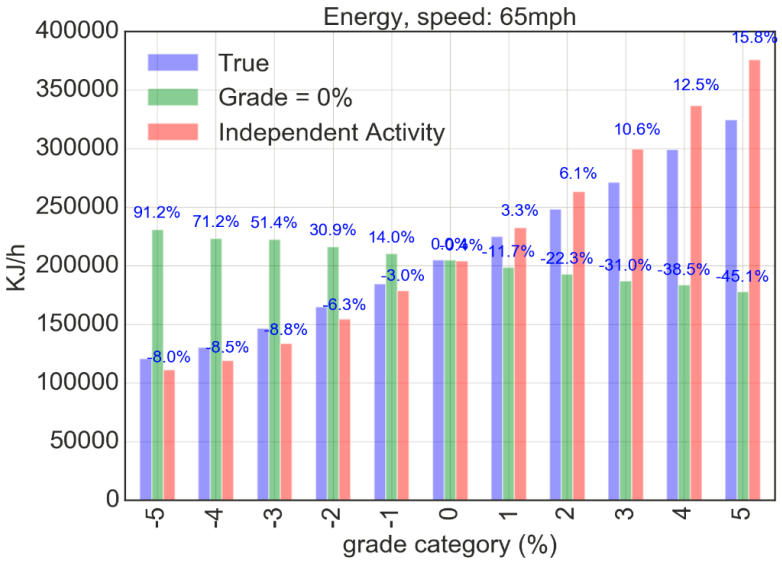


MARTA Acceleration Traces (0-40 mph) on Grades

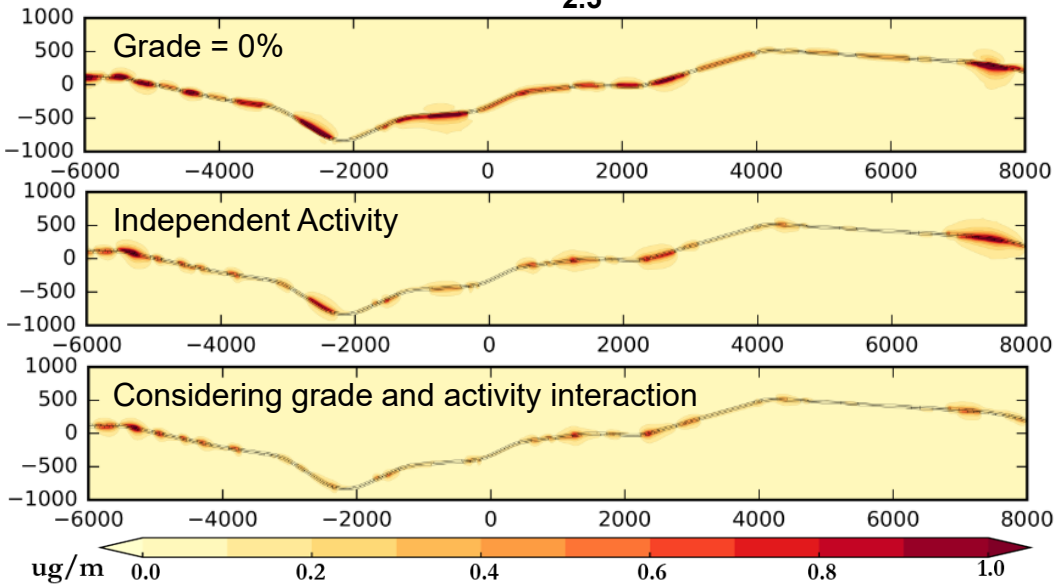


Impact of Road Grade on Energy and Air Quality Modeling

Energy Rate (KJ/hour)
65 mph Freeways - Passenger Cars



Absolute Difference
in Predicted $PM_{2.5}$ Concentration



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.

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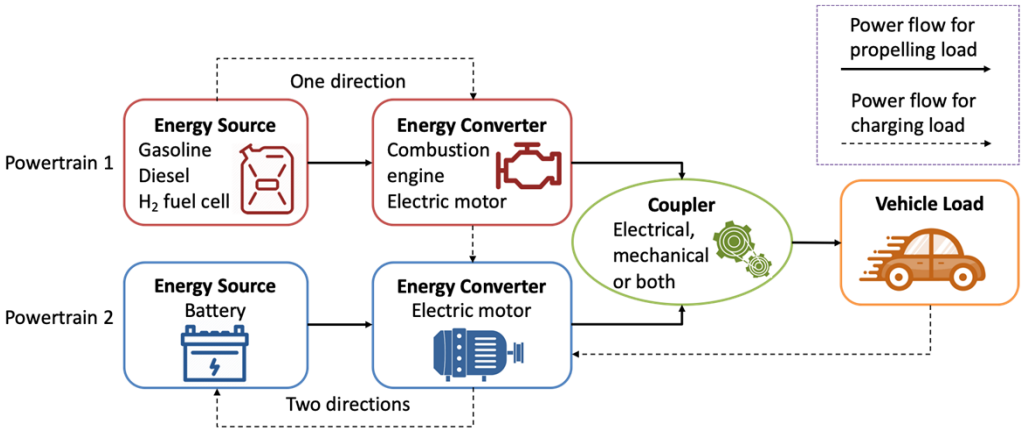
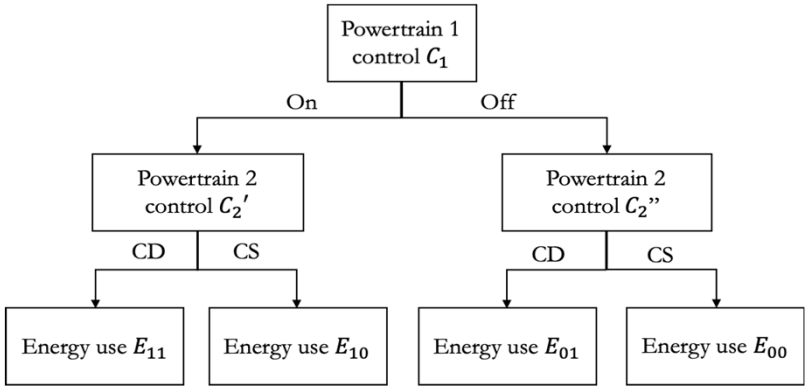
Simulation-Informed Energy Model for BEVs and Hybrids (with VSP Binning)

Conceptual Vehicle Framework



Source: Ehsani, et al., 2018

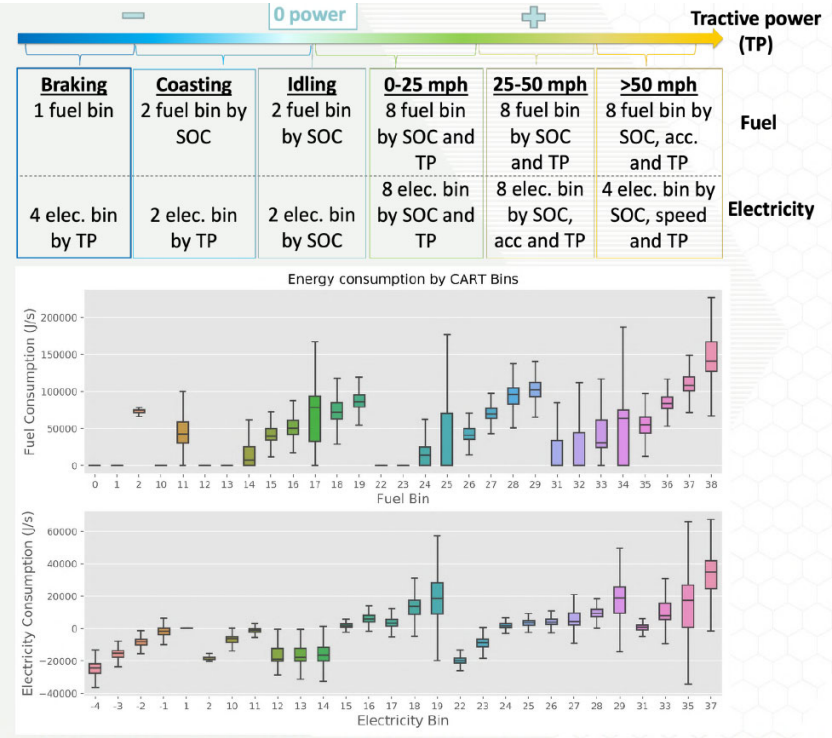
Bayesian Network Energy Modeling



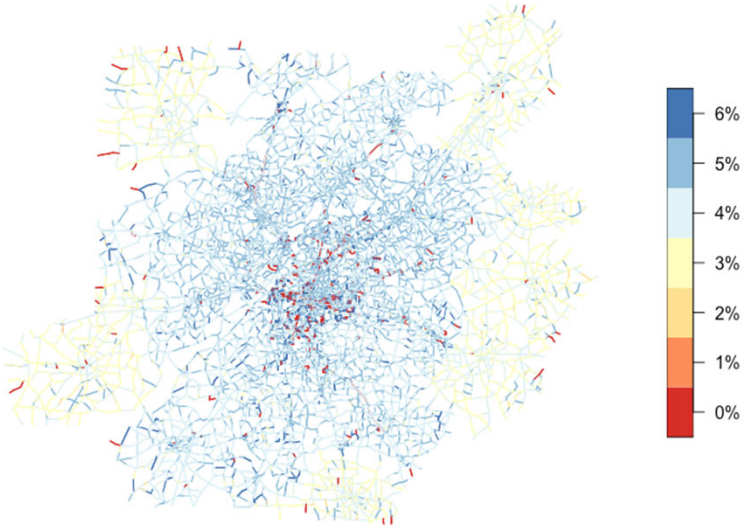
CD- charging depleting/ discharging
CS- charging sustaining/ charging

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 BEVs and Hybrids



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



Summary

- MOVES-Matrix (brute-force cluster modeling with MOVES)
  - Obtains exactly the same energy and emissions rates
- Can be applied at any spatial and temporal scale
  - Regional, corridor case studies, simulations, apps, etc.
  - Can link to dispersion modeling (AERMOD-Grid)
- Matrices are very large (Python scripts are required)
  - Python, distributed computing, GIS, visualization, traditional modeling (regional, simulation, dispersion)
- Big data and deep learning applications are evolving

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