Integrating Models at Multiple Scales for Transportation Energy and Emissions Assessment

Randall Guensler, Michael O. Rodgers, Michael Hunter, Angshuman Guin, Haobing Liu, Xiaodan Xu, Hanyan Li, Daejin Kim, Yingping Zhao, Cody Wang, Hongyu Lu

Georgia Institute of Technology
School of Civil and Environmental Engineering

Overview

- Modeling Tools
  - MOVES-Matrix for energy and emissions
  - Georgia Tech Fuel and Emissions Calculator (FEC)
  - Personal Vehicle Operating $Cost Calculator
- Applications:
  - Travel demand and activity-based modeling (ABM)
  - Traffic simulation models (Vissim™, DTA, etc.)
  - Monitored vehicle activity
  - North Avenue Smart Corridor application
  - Pollutant dispersion models (Caline4, AERMOD, etc.)
  - TransitSim/RoadwaySim
Modeling Tools

- 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.

\[
VSP = \left( \frac{A}{M} \right) v + \left( \frac{B}{M} \right) v^2 + \left( \frac{C}{M} \right) v^3 + \left( \frac{m}{M} \right) (a + g \cdot \sin \theta) v
\]
13 MOVES Source Types

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

Example CO₂ Emission Rates by VSP Bin for Passenger Trucks (2016MY in 2016)

\[ VSP = \left( \frac{A}{M} \right)^2 + \left( \frac{B}{M} \right)^2 + \left( \frac{C}{M} \right)^2 + \left( \frac{m}{M} \right) (a + g \cdot \sin \theta) v \]

23 operating mode bins
0 = braking, 1 = idle, 11 = coast, 21 = coast
Modeling of complicated and dynamic networks is tedious
- Many link emission rates are needed
- 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
Atlanta 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

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

Regional Matrix

Select sub-matrices

Query sub-matrix

Return fleet emission rate (weighted by onroad activity)

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

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

MOVES vs. MOVES-Matrix Results

- Results are exactly the same as MOVES GUI results

\[ y = 1x + 2E-07 \quad R^2 = 1 \]

\[ y = 1x - 3E-07 \quad R^2 = 1 \]

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

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
Vehicle $Cost Calculator
Inputs and Outputs (API Available)

Inputs

Enter Information

Choose Your Vehicle

Vehicle Make: [GA Nut]
Vehicle Model: [FORD F150]
Model Year: [2013]
Fuel Type: [Gasoline]
Hybrid Type: [Conventional Vehicle]

Parking Data

Monthly Parking Cost - Home ($) 600
Monthly Parking Cost - Work ($) 120
Monthly Parking Cost - Total ($) 720

Monthly Tolls Paid ($) 3.00

Output

Results

47.6¢/mile
Vehicle Ownership Cost

Depreciation: 41.48%
Insurance: 11.00%
Cost of gas: 11.59%
License: 5.45%
Smoke Check: 3.12%
Registration: 3.47%

The estimated total cost of owning and operating cost for the remaining useful life of 32.8 years is $37,001.

Modeling Applications
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
Modeling Spatial Structure

ARC Planning Network
74,469 Links
27,059 Nodes
5,873 TAZs

ABM15 Unconsolidated
202,994 Links
93,621 Nodes
5,873 TAZs

ABM15 Consolidated
131,864 Links
56,537 Nodes
5,873 TAZs

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

On-network

Off-network

Starts
Parked Vehicles
HC
PM$_{2.5}$
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

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 Corridor Application

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

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 CO₂ Emissions by Link
http://realtime.ce.gatech.edu/coa (Animation)

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

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

AERMOD Pollutant Concentration Screening 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)


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://movessensitvily.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

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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 the STM
  - Trajectories move through space and time
  - Accounts for congestion formation and dissipation
Space-Time Memory (STM)
100+ Elements for Deep Learning

- MOVES-Matrix (brute-force 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

Summary
Ongoing Work

- New dissertations and theses:
  - Road grade integration into the modeling tools
  - Hybrid/electric vehicles (Autonomie) into VSP framework
  - Transit fleet optimization model (for EV integration)
- Forthcoming
  - Distributive justice assessment tools for planning
  - Pollutant exposure assessment tools for health effects