Integrated Agent-Based Travel Behavior, Dynamic Traffic, and Emissions Modeling for Planning, Operations and TSM&O Applications

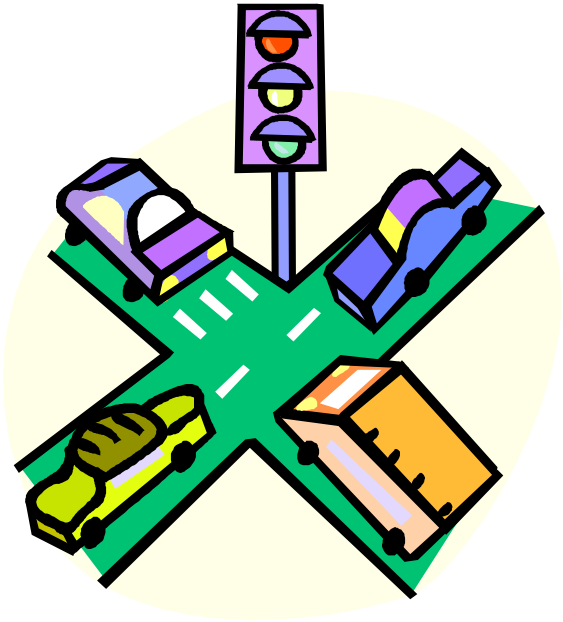
Lei Zhang, Chenfeng Xiong, Carlos Carrion
University of Maryland, College Park
Xuesong Zhou
Arizona State University
Nagui Rouphail, H. Christopher Frey, Bin Liu, Shams Tanvir
North Carolina State University

Outline

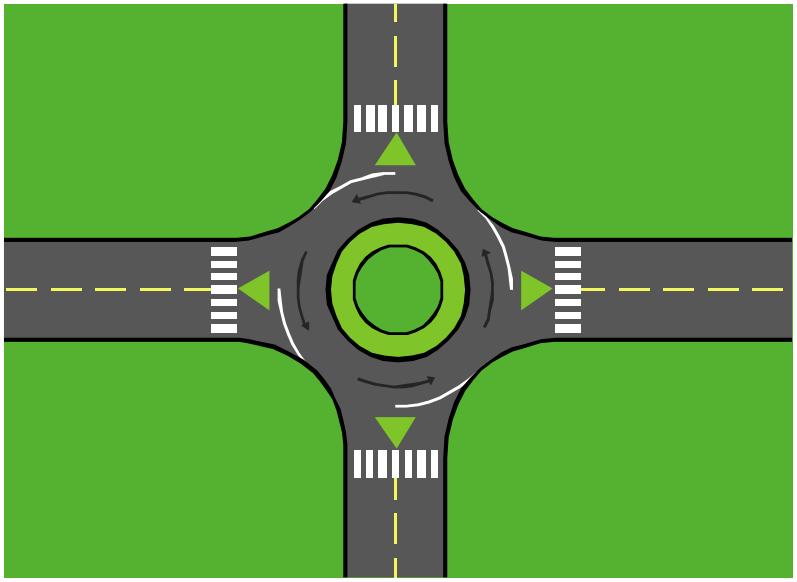
- Introduction
- Simplified Emission Estimation Method: MOVESLite
- MOVESLite + DTALite
- SILK AgBM + DTALite + MOVESLite
- Numerical Test – SILK AgBM + DTALite + MOVESLite

Introduction

- **Integrated simulation models quantify the effect of infrastructure design, traffic control measures, and other policies on vehicle dynamics (i.e. speed and acceleration of individual vehicles) and traveler behaviors (i.e. route choice, departure time choice…)**



vs.



Introduction – Emission Models

- **Macroscopic emission models**
  - **Regulatory model from US EPA: MOBILE 6**
  - **California EMFAC (EMission FACtor)**

- **Microscopic emission models**
  - **Regulatory model from US EPA: MOVES (Motor Vehicle Emission Simulator)**
  - **California's CMEM (Comprehensive Modal Emissions Model)**

Microscopic Emission Models

- First developed by Jimenez (1998) to understand and quantify motor vehicle emissions
- Emission rate data binning by operating modes as well as VSP (Frey et al., 2002)
- Can output fine-scale information, such as second by second resolution emissions

VSP Formulation

Vehicle Specific Power

- **Accounts for changes in kinetic energy, potential energy, rolling resistance, and aerodynamic drag**
- **Function of speed, acceleration, grade**

$$VSP = v\left\{(1+\varepsilon)a + g\left(\frac{r}{100}\right) + gC_r\right\} + \frac{1}{m}\frac{\rho_{air}}{2}AC_d v^3$$

a	= vehicle acceleration (m/s^2)	r	= road grade (%)
A	= vehicle frontal area (m^2)	v	= vehicle speed (m/s)
C_d	= aerodynamic drag coefficient	VSP	= Vehicle Specific Power (kW/ton)
C_r	= rolling resistance coefficient (0.0135)	ε	= rotational masses factor (~ 0.1)
g	= acceleration of gravity (9.81 m/s^2)	ρ_{air}	= air density (1.207 kg/m^3 at 20 °C)
m	= vehicle mass (metric tons)		

- **Well-demonstrated excellent predictor of energy use**
- **Good predictor of tailpipe exhaust emissions (i.e. CO_2, CO, Hydrocarbons, NO_x, Particulate Matter)**

Emission Binning by Operating Mode

- **Operating mode is determined by VSP and speed**

0 mph < v_i ≤ 25 mph		25 mph < v_i ≤ 50 mph		v_i > 50 mph	
OpMode ID	Description	OpMode ID	Description	OpMode ID	Description
11	VSP< 0	21	VSP< 0		
12	0≤VSP< 3	22	0≤VSP< 3		
13	3≤VSP< 6	23	3≤VSP< 6	33	VSP< 6
14	6≤VSP< 9	24	6≤VSP< 9	35	6≤VSP<12
15	9≤VSP<12	25	9≤VSP<12		
16	12≤VSP	27	12≤VSP<18	37	12≤VSP<18
Other:		28	18≤VSP<24	38	18≤VSP<24
0	Braking	29	24≤VSP<30	39	24≤VSP<30
1	Idling	30	30≤VSP	40	30≤VSP

v_i: instantaneous speed of the ith second

- **Emission rates are classified by vehicle type and operating mode**

Vehicle Type	Age	Operating Mode	Energy (KJ/h)	CO2 (g/h)	NOX (g/h)	CO (g/h)	HC (g/h)
1	0	0	49206.3	3536.29276	0.05385	2.36609	0.039171
1	0	1	45521.4	3271.47128	0.008979	4.05557	0.000418
1	0	11	71581.4	5144.316613	0.146868	6.52187	0.022892
1	0	12	98841	7103.3732	0.155233	2.82379	0.02085
1	0	13	137367	9872.1084	0.363034	9.76815	0.052262
1	0	14	173571	12473.9692	0.657844	14.2137	0.072532
1	0	15	206979	14874.8908	1.18797	20.8813	0.103686
1	0	16	249989	17965.87613	2.5348	35.985699	0.171948
1	0	21	97382.5	6998.555667	0.254133	5.8165	0.038721
1	0	22	110849	7966.348133	0.357951	9.33417	0.046237
1	0	23	135007	9702.503067	0.508789	13.1798	0.06505
1	0	24	173205	12447.666	0.930889	25.9039	0.115221
1	0	25	231143	16611.47693	1.52098	18.526501	0.124367

MOVESLite

- **MOVES**
  - **Computationally and data intensive model**
  - **An extremely detailed emission rate inputs**
  - **Querying database is slow**
  - **Very difficult to link with a traffic simulation model**

- **MOVES Lite**
  - **A simplified and light-weight version of MOVES developed by NCSU (Frey, Rouphail, Liu 2010)**

MOVES Lite Conceptual Overview

INPUTS

- Vehicle Type
- Vehicle Age
- Vehicle Fuel
- Trajectory
- Ambient Conditions
- I/M Program

INTERNAL DATA

- Default Modal Rates
- Base Cycle

CALCULATIONS

Cycle Correction Factor

$$CCF_{p,c,a,v} = \left(\frac{\left(\sum_m f_m^c \times ER_{p,a,v,m}\right)}{\left(\sum_m f_m^b \times ER_{p,a,v,m}\right)} \right) \left(\frac{V^b}{V^c} \right)$$

Cycle Average Emission Rate

$$CE_{p,c} = \sum_v \left\{ \left[\sum_a \left(EF_{p,b,a,v} \times CCF_{p,c,a,v} \times f_{a,v} \right) \right] \times f_v \right\}$$

OUTPUTS: Energy, CO_2, CO, HC, NO_x, PM

Emission Estimation by MOVESLite

- Input data
  - Second-by-second vehicle speed and acceleration

- Step 1: calculate VSP;
- Step 2: VSP + speed -> operating mode
- Step 3: operating mode +speed -> average energy consumption rate and emission rates;
- Step 4: accumulate the second-by-second emission results

- Output
  - Energy consumption, CO2, NOx, CO and HC

MOVES Lite Vs. MOVES: Accurate

Average of Errors of the Simplified Model

Vehicle Types	Average Percent Error: Simplified vs. MOVES Models, All Selected Cycles			
	CO_2	NO_x	CO	HC
Passenger Car (PC)	0.02	0.03	0.02	0.04
Passenger Truck (PT)	0.01	-0.22	-0.07	0.17

18 driving cycles each for PC, PT

Ages: 0, 5, 10, 15 years (2011 calendar year).

MOVES Lite vs. MOVES: Fast

MOVES Lite Runs 3,000 Times Faster Than MOVES

- Simplified Model is implemented using MATLAB/C++
- Estimating emission factors for 18 driving cycles

MOVESLite	MOVES
1 seconds	10 minutes

DTALite + MOVESLite

DTALite – Open Source Engine (C++)

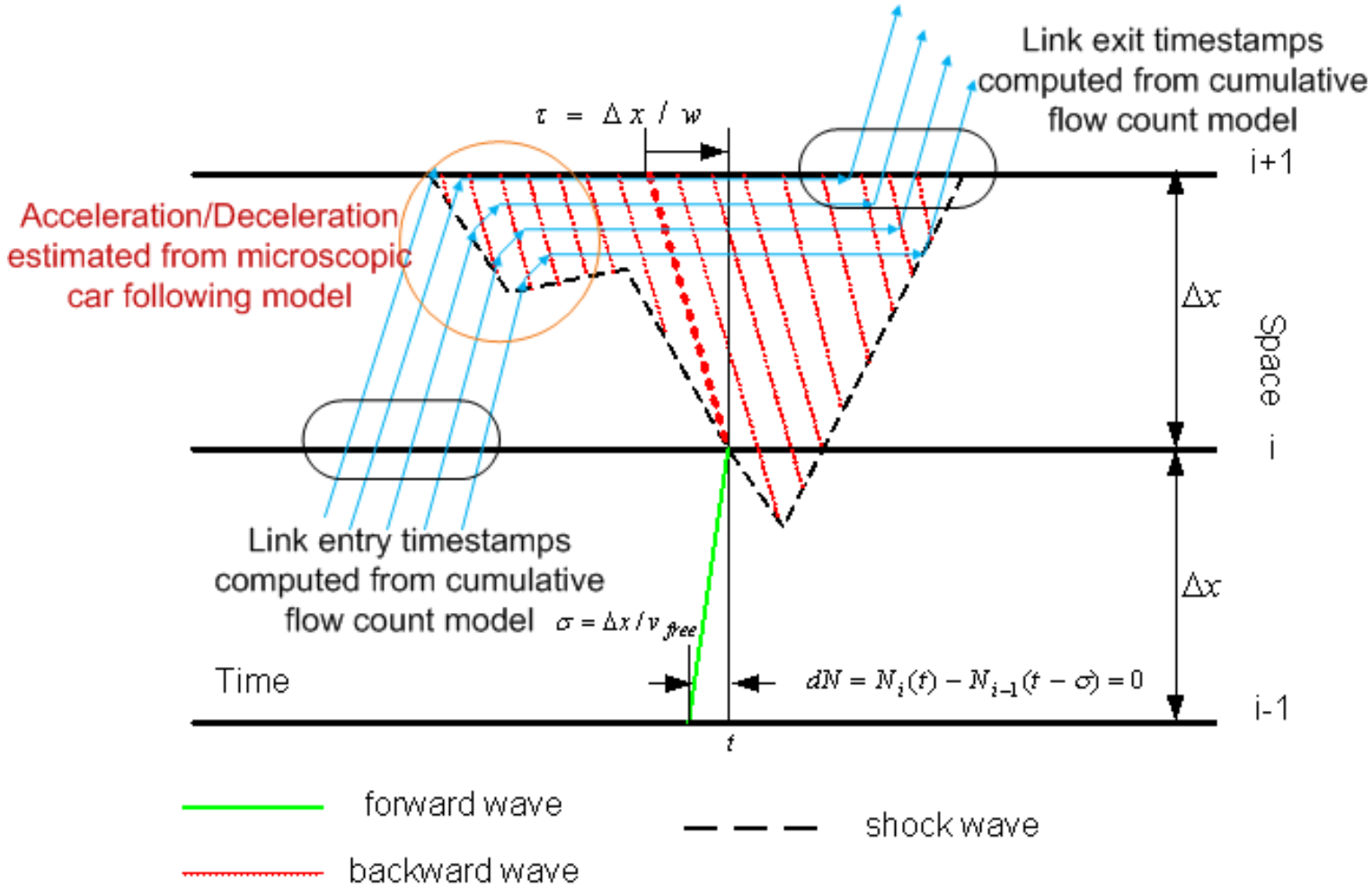
- Lightweight agent-based DTA
- Capacity constrained
- Built-in OD Matrix estimation program (ODME)
- Traffic simulation models
  - BPR, volume-delay functions
  - Point-Queue
  - Spatial Queue (w/ jam density)
  - Newell's model (kinematic wave model)

DTALite + MOVESLite

DTALite – Open Source Engine (C++)

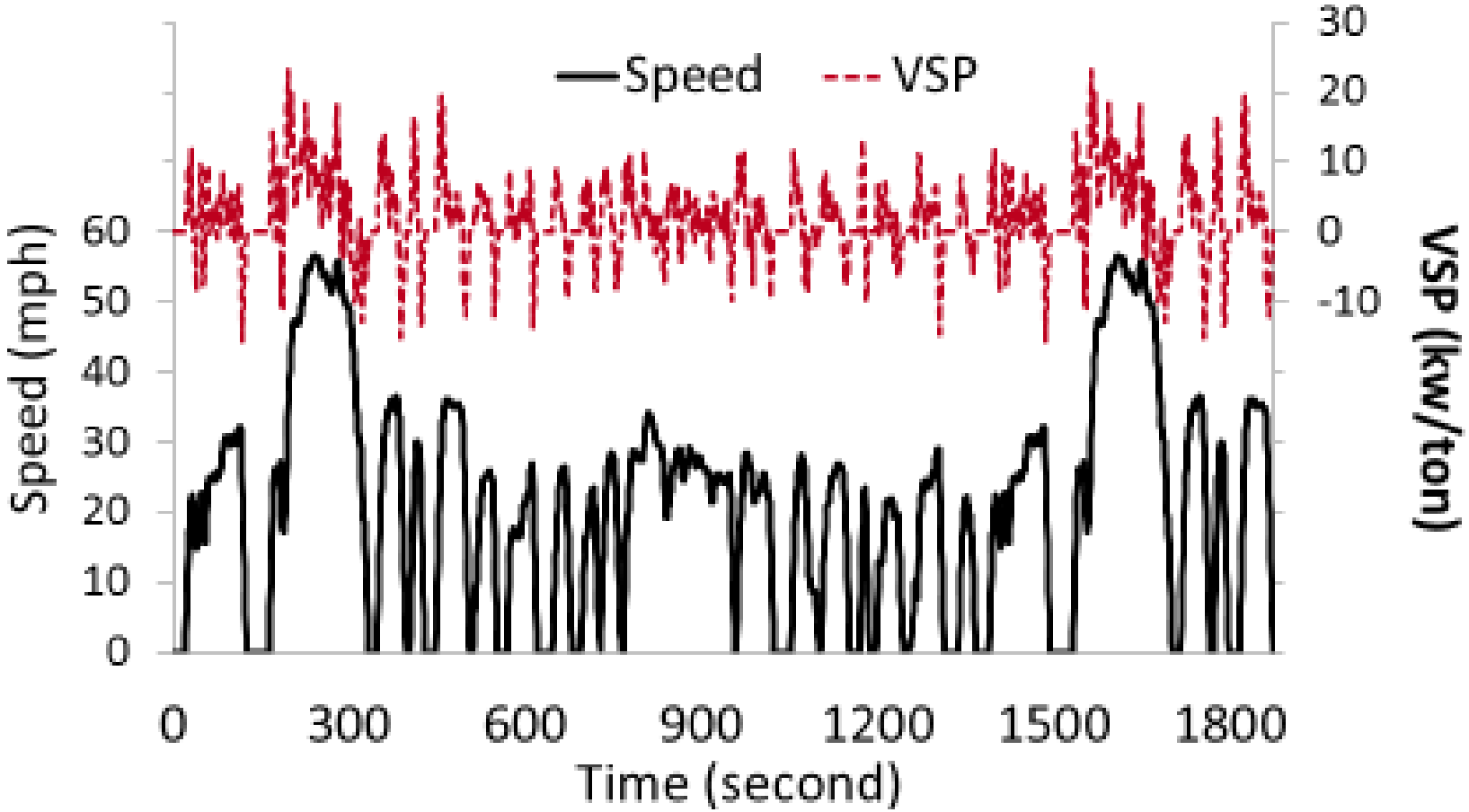
- Given a set of link-based mesoscopic traffic simulation results from DTALite
- Apply a simple linear car-following model (LCF) proposed by Newell(1962, 2002) to generate second-by-second detailed vehicle trajectories with corrections for unrealistic acceleration and deceleration.

DTALite + MOVESLite



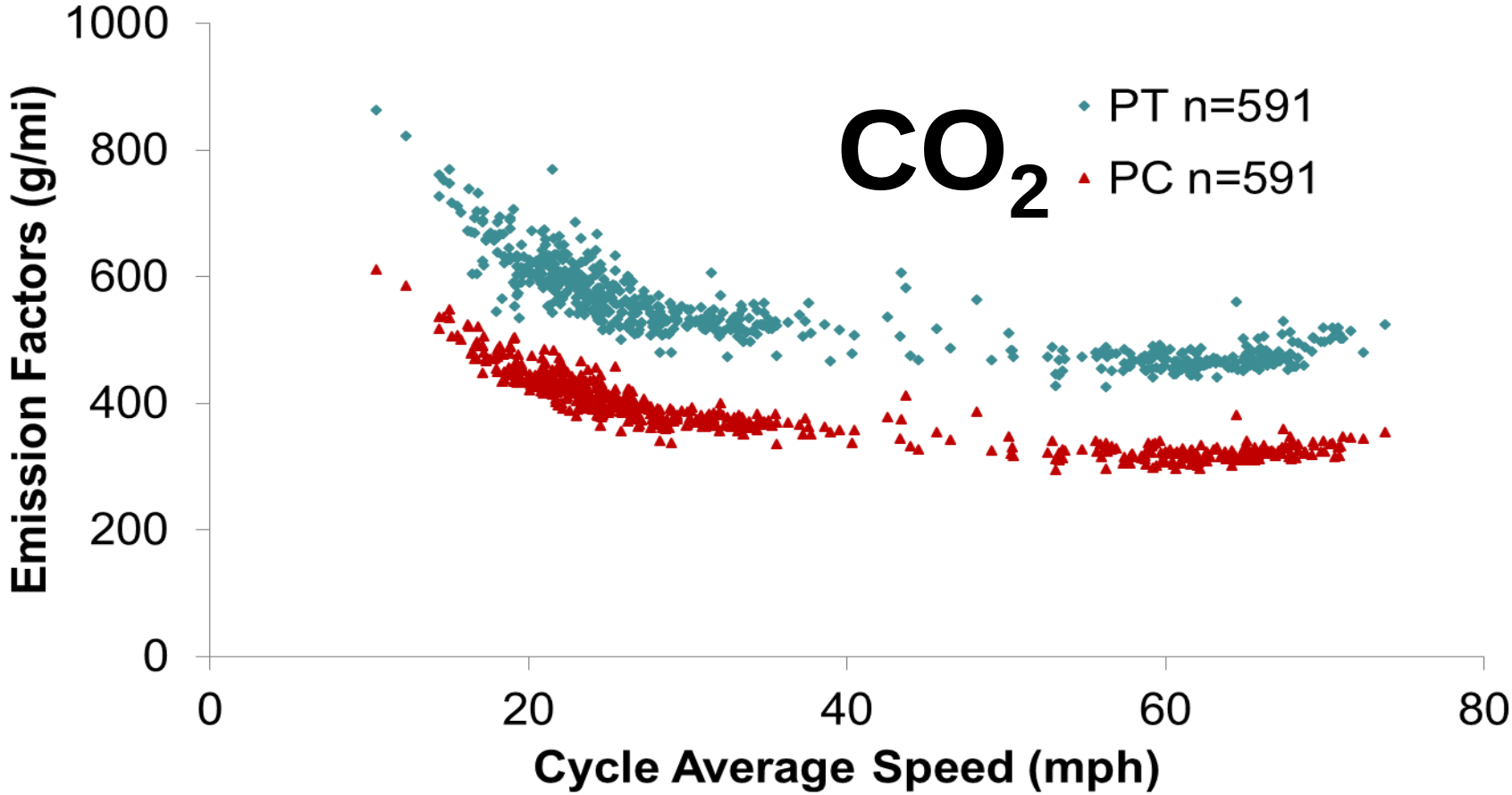
Trajectories → VSP → Energy

Any Vehicle Trajectory Can Be Converted to VSP-Based Modal Rates



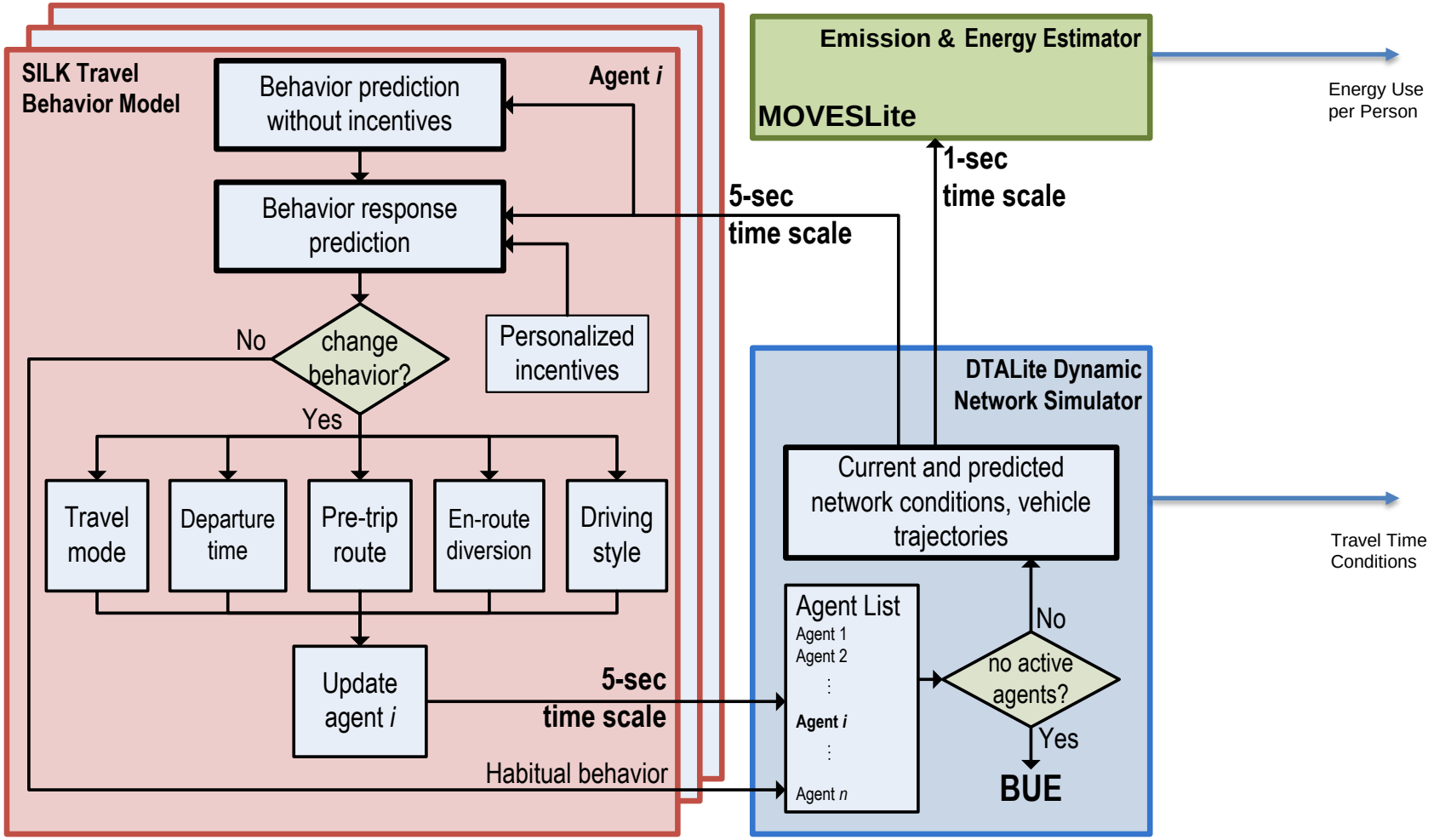
Sensitivity to Real-World Driving

VSP Distribution, not Just Average Speed, Predicts Energy Use and Emissions



Liu (2015), *Quantification and Evaluation of Onroad Light Duty Vehicle Tailpipe Emissions*, Ph.D. Dissertation, NCSU.

SILK AgBM + DTALite + MOVESLite



SILK AgBM + DTALite + MOVESLite

- **Behavioral + Traffic Flow + Emission Models**

- **Integrated framework to evaluate traffic control measures, emission and energy benefits, policies targeting multi-dimensional travel behavior.**

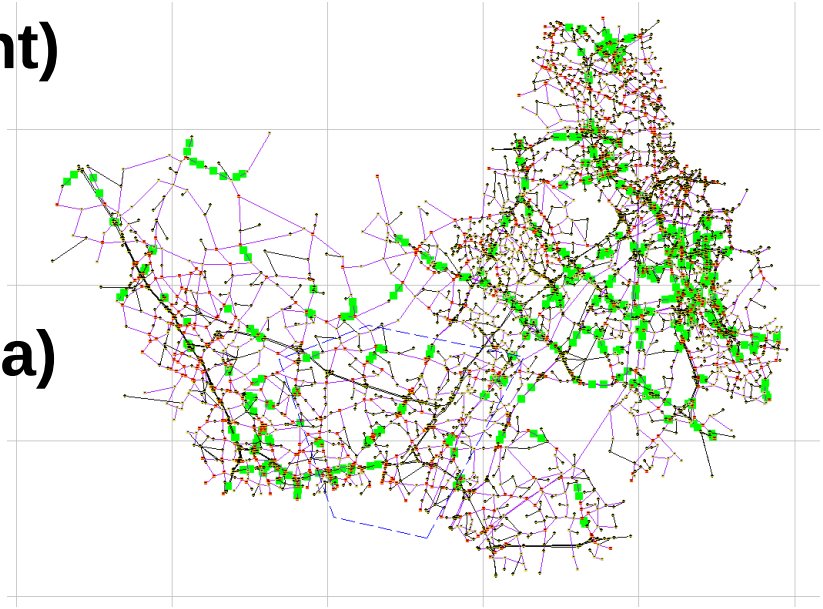
- **Currently being deployed for a research project for developing personalized real-time traveler information and incentives. See ipretii.umd.edu**

- **Funded by US DOE**
  ARPA-E TRANSNET Program
  USD $4.5 Million

Numerical Test: Integration

A sub-area model of DC-Baltimore:

- Simulating PM (3pm – midnight)
- 10,000 links
- 712 traffic zones
- 2 million agents
  (25% of the DC-Baltimore Area)
- 20% technology users



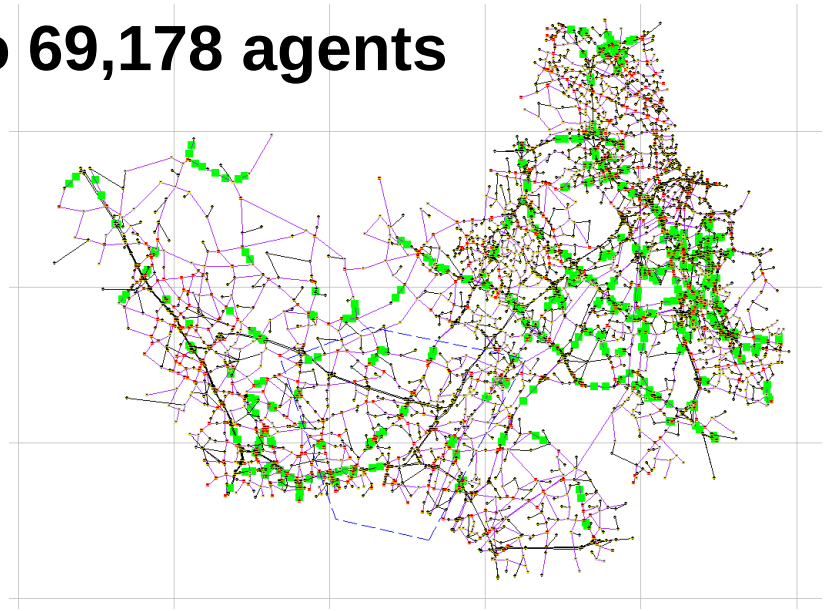
Testing one full iteration:

- **Initialization:** *population, path generation*
- **SM DTALite/MOVESLite:** *traffic and energy simulation*
- **SM AgBM:** *non-users travel behavior*
- **SM AgBM:** *incentive allocation for technology users*
- **CA:** *incentive optimization and database API for deployment*

Numerical Test: Integration

Integration Findings:

- CA has allocated incentives to 69,178 agents
- 3.5% of total population
- 17.5% of technology users



Energy Saving Potential:

- 8.2% reduction in overall transportation energy from incentivized agents

Thank You!

Questions, Comments, and Suggestions are Welcome. Please Contact:

Lei Zhang, Ph.D.
Herbert Rabin Distinguished Professor
Director, National Transportation Center

Department of Civil and Environmental Engineering

1173 Glenn Martin Hall, University of Maryland

College Park, MD 20742

Email: lei@umd.edu

Phone: 301-405-2881

Web: http://www.lei.umd.edu
Center: http://www.ntc.umd.edu