Mobility and Emissions Modeling of Automated Vehicles

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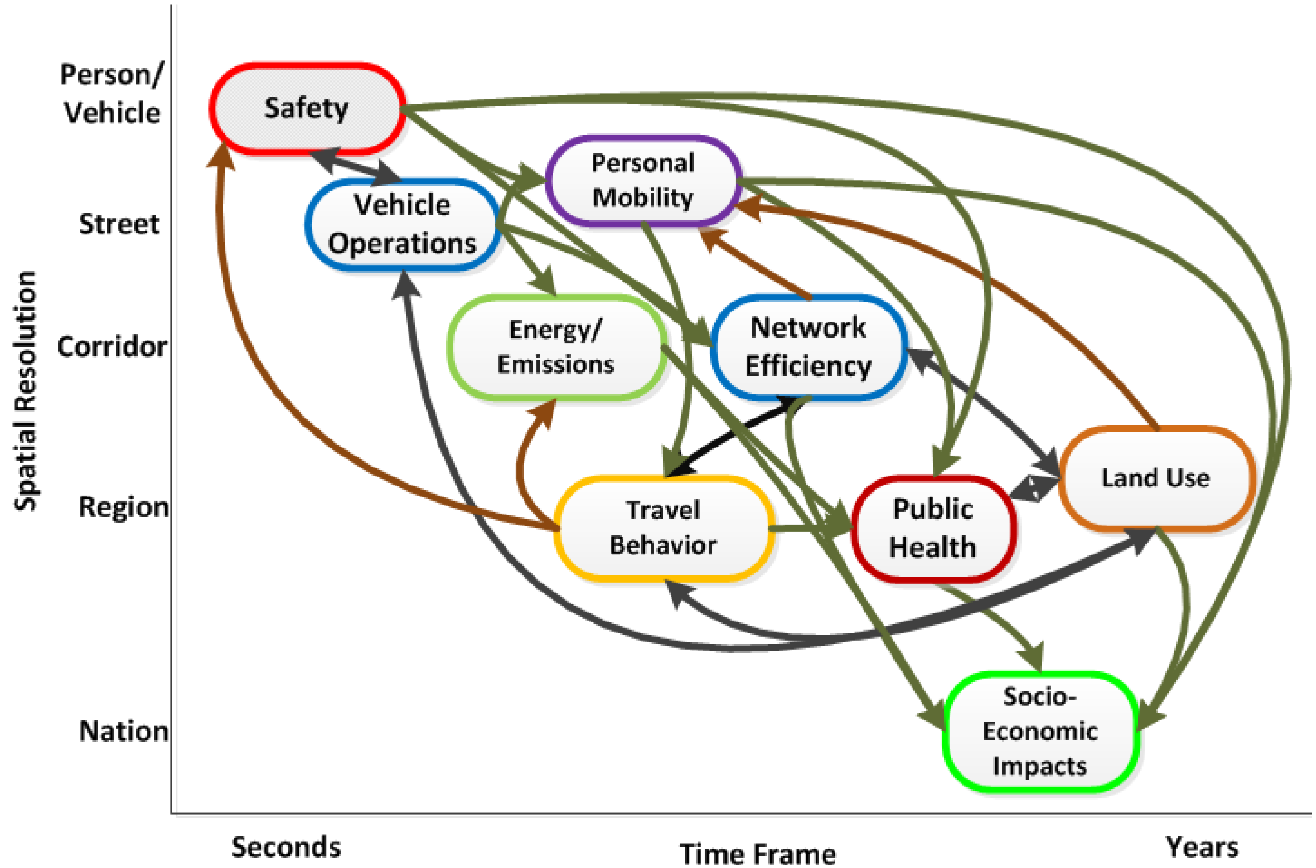
Outline

- US DOT Automated Vehicle Benefits Framework
- Traffic Microsimulation Modeling
- Energy and Emissions Inventory Modeling
- AV Scenario Results
- Effects on Travel Behavior
- Next Steps

Framework for Automated Vehicle Benefits

- "Big picture" of automated vehicle impacts
- Short-term direct impacts
- Longer-term indirect impacts

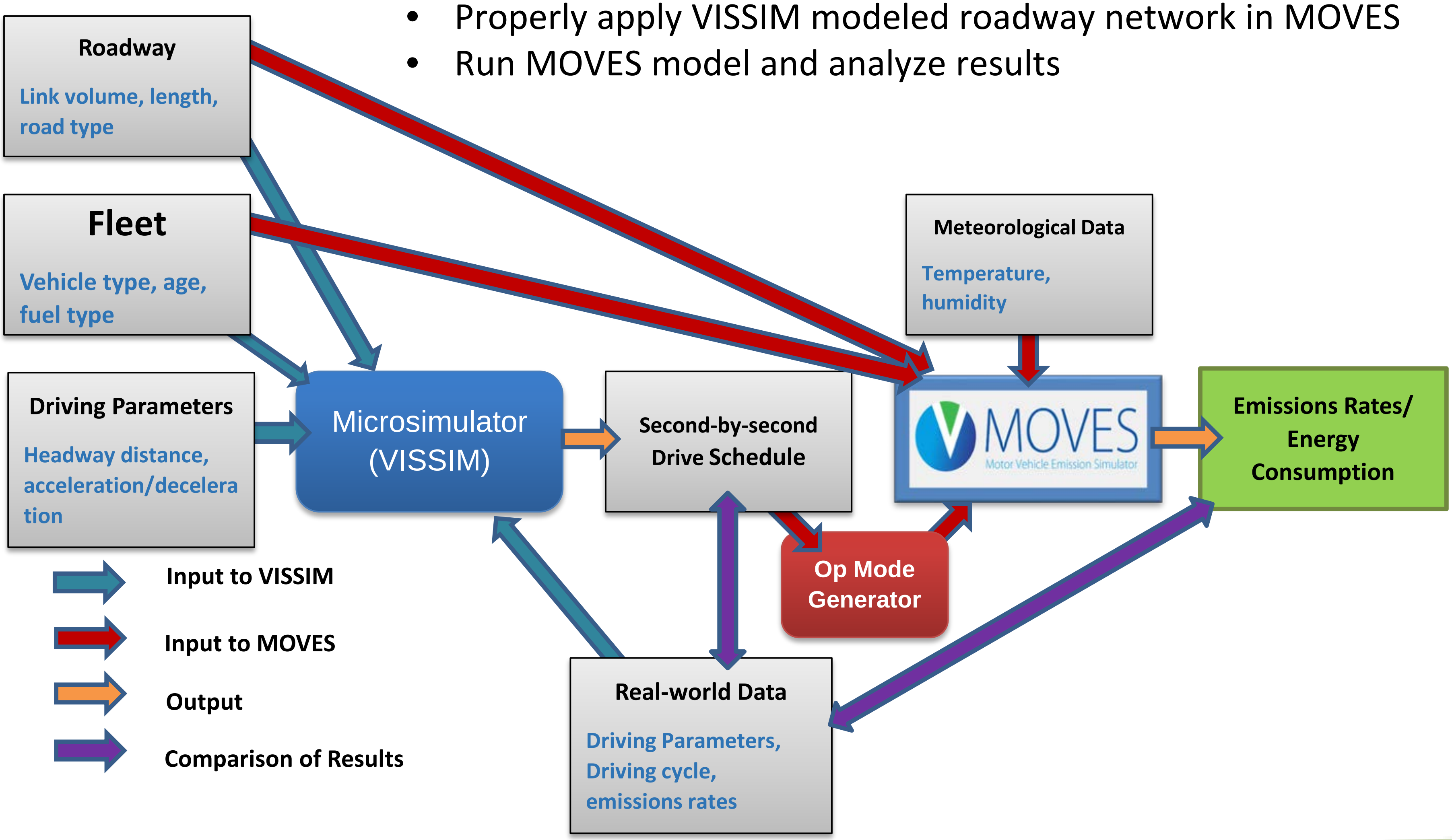


Framework Development

- Standardized approach: facilitates comparability among the research community
- Existence of recognized and accepted tools/models (i.e. US EPA MOVES), assists in the development of a framework
- There is no gold standard microsimulation tool; they all have fundamental differences. Therefore, we must do the following:
  - Define/set baseline assumptions (acceptable headway, min/max acceleration, etc.)
  - Standardize simulation inputs and result formats (run time, time per step, units, etc.)
  - Identify common networks (the design of the road/network is an important factor)
- ***Performance validation and testing***

Modeling Approach

- Process VISSIM output to create operating mode distributions
- Properly apply VISSIM modeled roadway network in MOVES
- Run MOVES model and analyze results



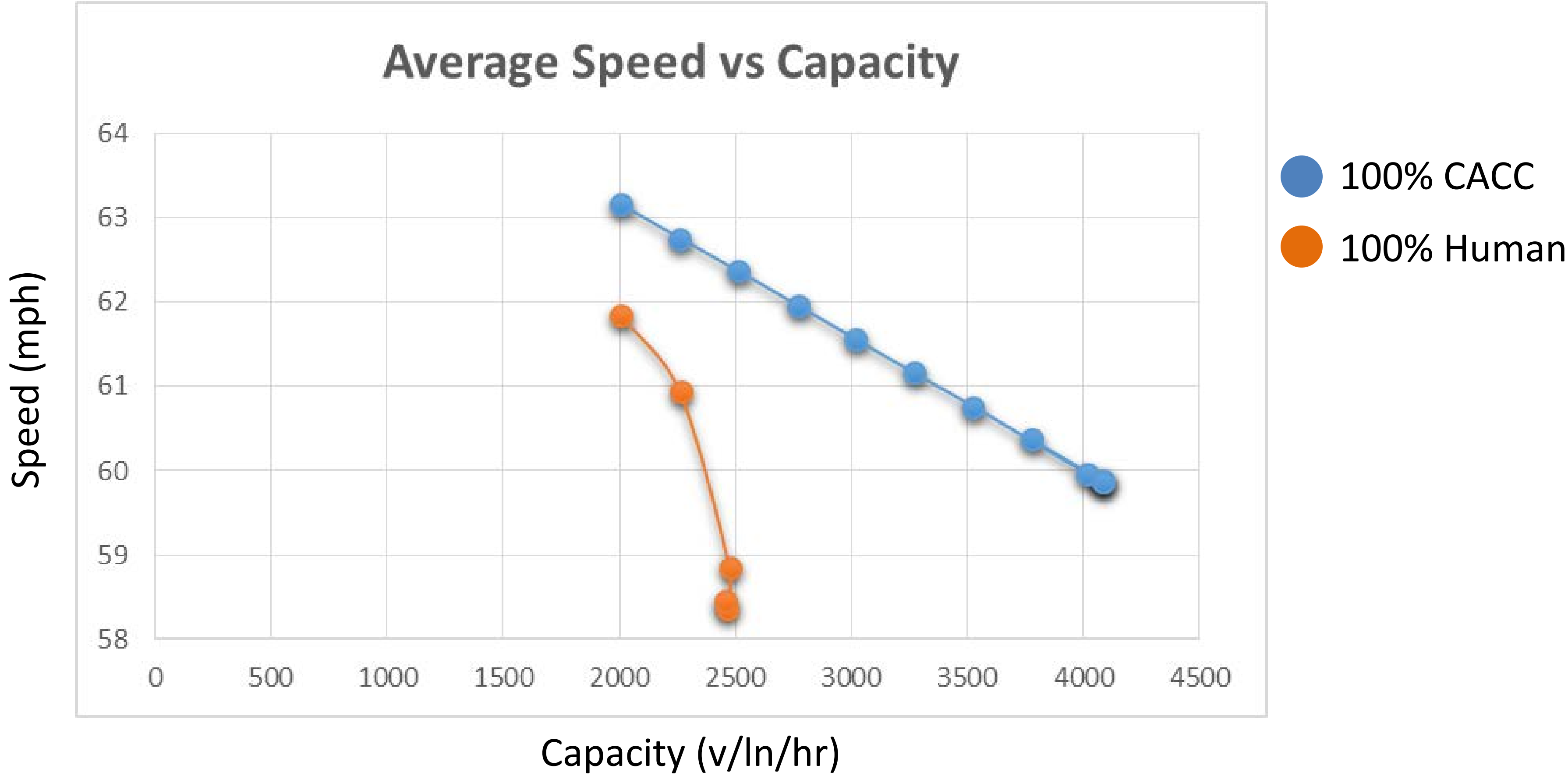
Vehicle Automation Scenarios

- Modeled passenger cars on two-mile segment of two-lane highway
- Ran four different microsimulation scenarios in VISSIM:
  1) 100% human driving at 2400 vehicles/lane/hour
  2) 100% driving with coordinated adaptive cruise control (CACC) at 2400 v/l/h
  3) 50% CACC & 50% human driving at 2400 v/l/h
  4) 100% CACC driving at 4000 v/l/h
- MOVES project-level emissions calculated for each scenario and normalized for activity (grams/mile)

Defining CACC

- Modified coordinated adaptive cruise control (CACC) model from Turner-Fairbank Highway Research Center (DOT)
  - No managed lane
  - No platoon formation logic
- Switched car-following logic based on leading vehicle:
  - If a CACC-enabled car is following another automated enabled vehicle, it will follow in CACC mode (i.e. shortened headway)
  - If the vehicle in front of a CACC-enabled car is not CACC enabled, it will operate according the ACC

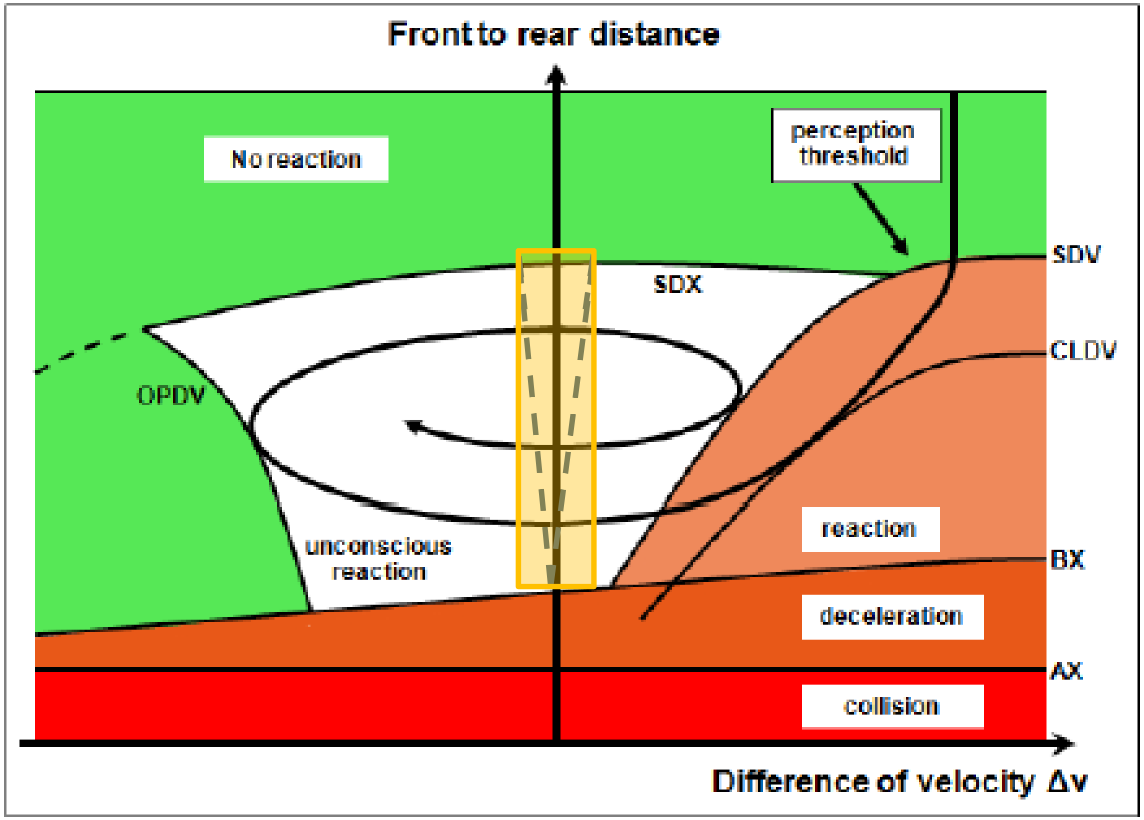
Typical Mobility Results Report



- Report the average results over 10-15 runs
- But how are the vehicles behaving?

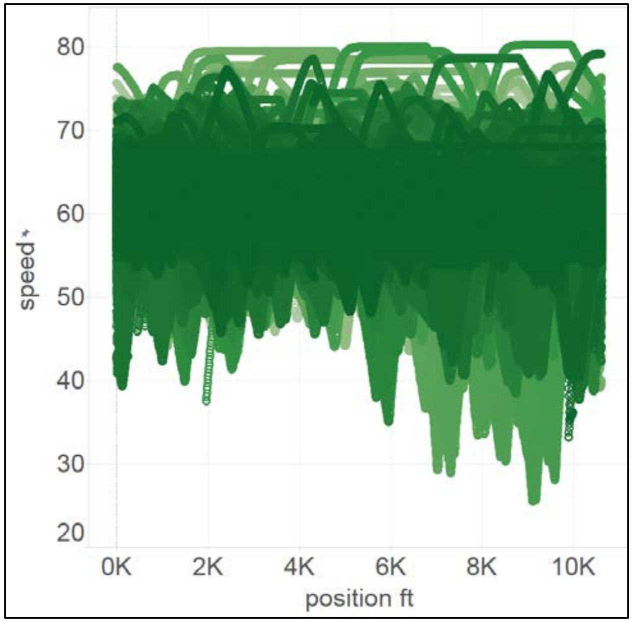
Weidemann Car Following

- A closer following headway
- The reduction of oscillations in driver car following behavior



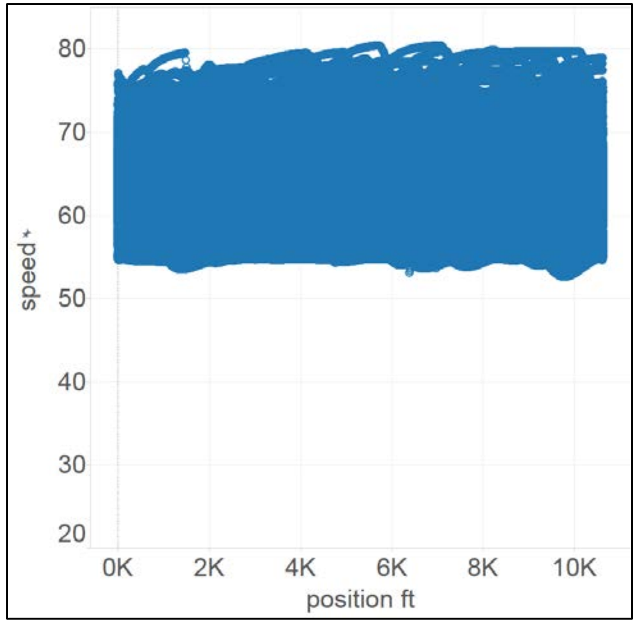
[Capri (2012), International Journal of Traffic and Transportation Engineering]

100% Human Drivers
2400 v/ln/hr



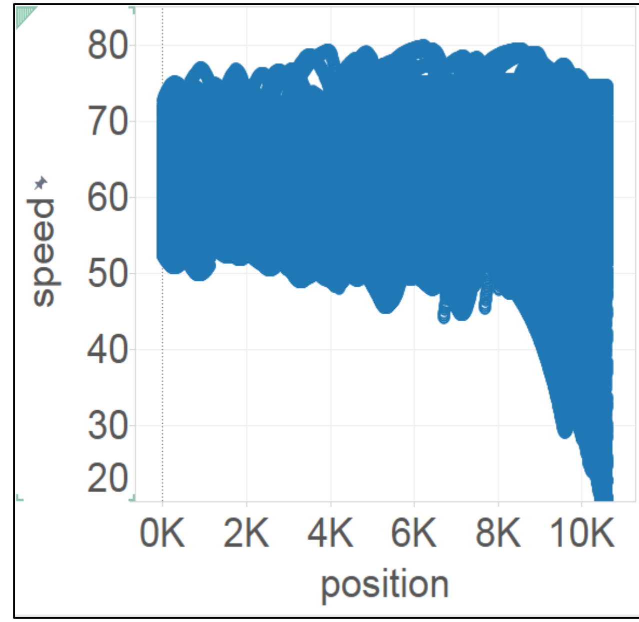
V/C ratio ~1

100% CACC Automated
2400 v/ln/hr



V/C ratio ~0.6

100% CACC Automated
4000 v/ln/hr



V/C ratio ~1

- 100% CACC automated can significantly increase lane capacity
- Emission results will be highly sensitive to V/C ratio
- Average speed is too high level to describe results
- Work in this area will focus on identifying a standardized set of visualizations

MOVES Operating Modes

- Vehicle-specific power (VSP) and emissions are well correlated
- VSP is derived from instantaneous speed and acceleration along with other constants such as vehicle mass and aerodynamic drag
  - Able to handle modal data at 1 Hz or higher frequencies
- MOVES operating modes assigned according to VSP and speed bins
  - Separate op modes for braking and idling
- Operating mode distributions by time spent in mode can be developed from GPS or microsimulation data
  - MOVES can model emissions of VISSIM scenarios at project scale

Operating Modes for Running Emissions

VSP Class (kW/tonne)	Speed Class (mph) 1-25	25-50	50 +
30 +	16	30	40
27-30			
24-27		29	39
21-24		28	38
18-21			
15-18			37
12-15		27	
9-12	15	25	
6-9	14	24	35
3-6	13	23	
0-3	12	22	33
< 0	11	21	

Beardsley (2011), MOVES Workshop

Vehicle-Specific Power (VSP)

$$P_{V,t} = \frac{Av_t + Bv_t^2 + Cv_t^3 + mv_t a_t}{m} \qquad \textbf{Equation 1-2}$$

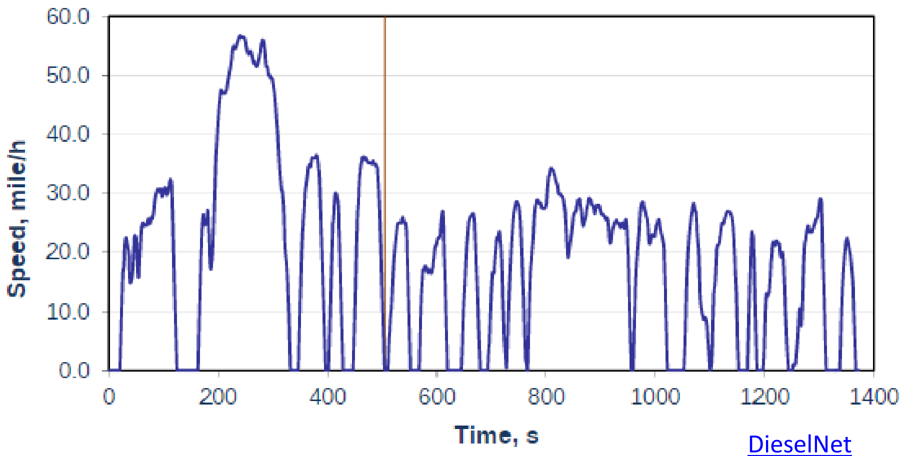
In this form, VSP ($P_{V,t}$, kW/Mg) is estimated in terms of vehicles':

- speed at time t (v_t, m/sec),
- acceleration a_t, defined as $v_t - v_{t-1}$, (m/sec^2) ,
- - mass m (Mg) (usually referred to as "weight,"),
- - track-road load coefficients A, B and C, representing rolling resistance, rotational resistance and aerodynamic drag, in units of kW-sec/m, kW-sec^2/m^2 and kW-sec^3/m^3, respectively.[3]

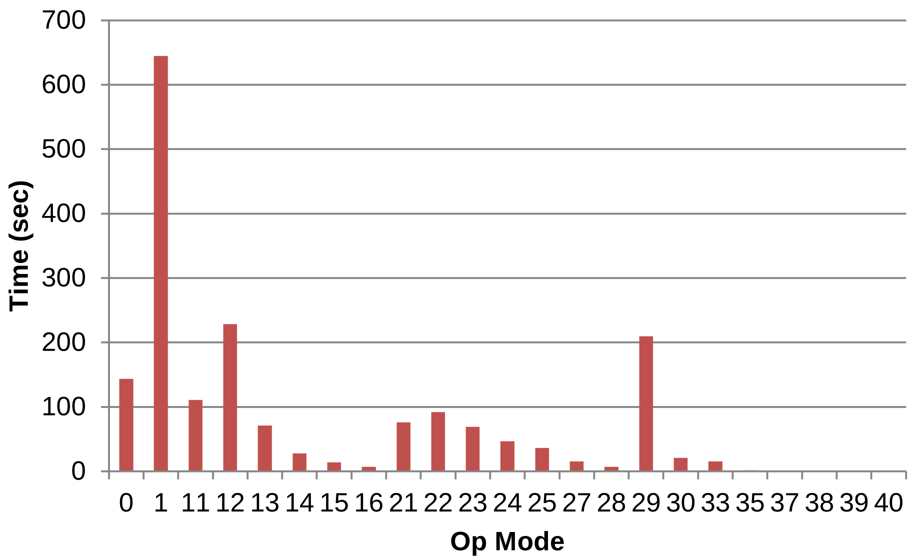
MOVES2014 LDV Emissions Technical Report

Corresponding Drive Cycle and Operating Mode Distribution

- Example: bus driving within a city
  - Urban Dynamometer Driving Schedule (UDDS)

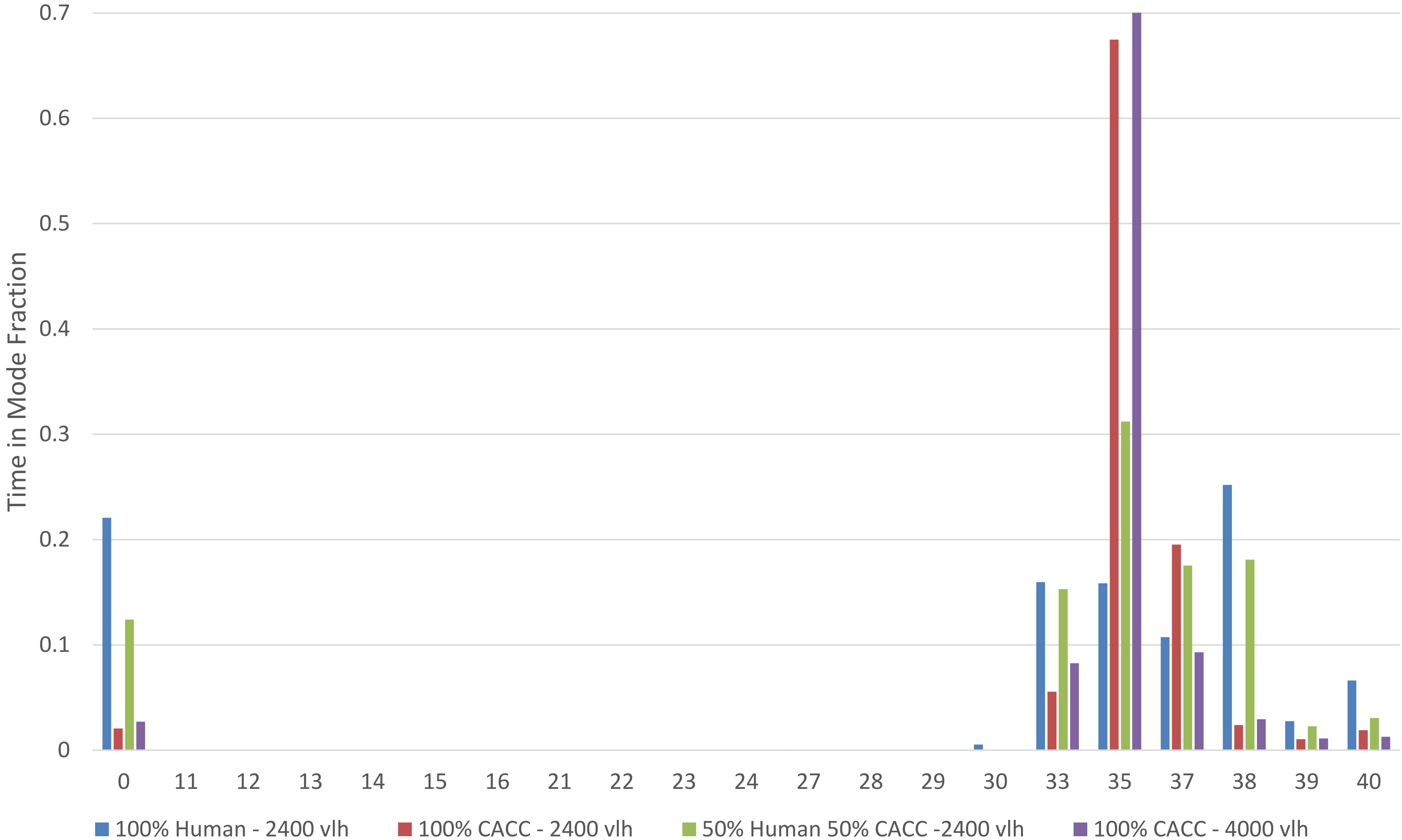


DieselNet

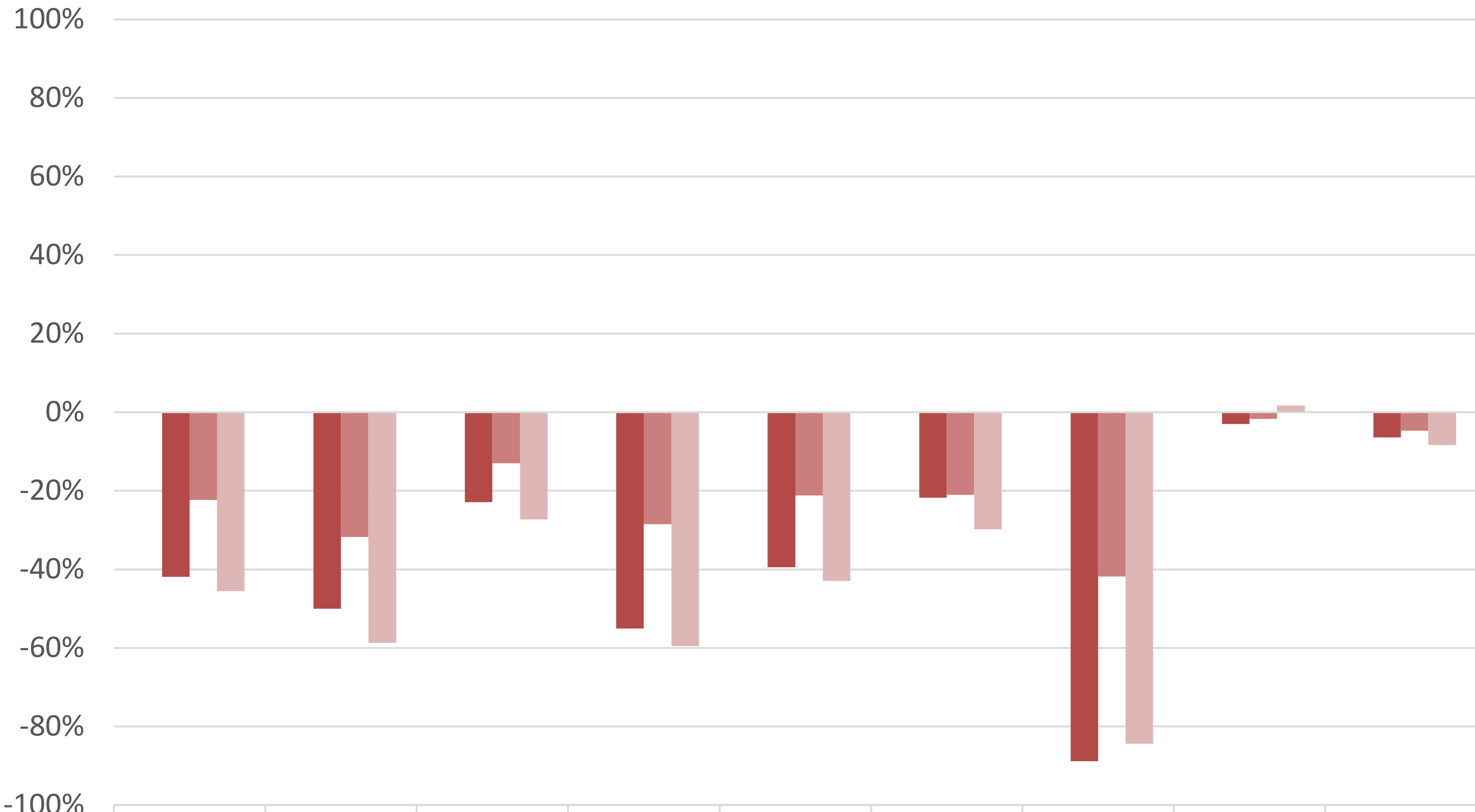


Eilbert (2013), CRC Real-World Emissions Workshop

Human vs. CACC Operating Mode Distributions



Percent Reductions in Emissions per Vehicle from 100% Human Driving



	Total Hydrocarbons (THC)	Carbon Monoxide (CO)	Nitrogen Oxides (NOx)	Methane (CH4)	Volatile Organic Compounds (VOC)	Particulate Matter < 2.5µm (PM2.5)	Brakewear (PM2.5)	Tirewear (PM2.5)	Energy/Carbon Dioxide (CO2)
100% Human - 2400 vlh	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
100% CACC - 2400 vlh	-41.9%	-50.0%	-22.9%	-55.0%	-39.5%	-21.7%	-88.8%	-3.0%	-6.4%
50% Human/50% CACC - 2400 vlh	-22.3%	-31.7%	-13.0%	-28.5%	-21.2%	-21.1%	-41.8%	-1.7%	-4.7%
100% CACC - 4000 vlh	-45.6%	-58.7%	-27.2%	-59.6%	-43.0%	-29.8%	-84.4%	1.7%	-8.3%

Conclusions

- Intuitive results
  - With the same traffic volume, emissions are least for the 100% CACC scenario and are most for the 100% human driving scenario

- Why?
  - Emission rates (g/mi) are less for CACC than human driving when normalized for activity, but absolute emissions may not be less
  - Human driving shows more braking and changes in speed and VSP than CACC
  - A high percentage of CACC driving falls into operating mode 35 with speeds greater than 50 mph and moderate VSP

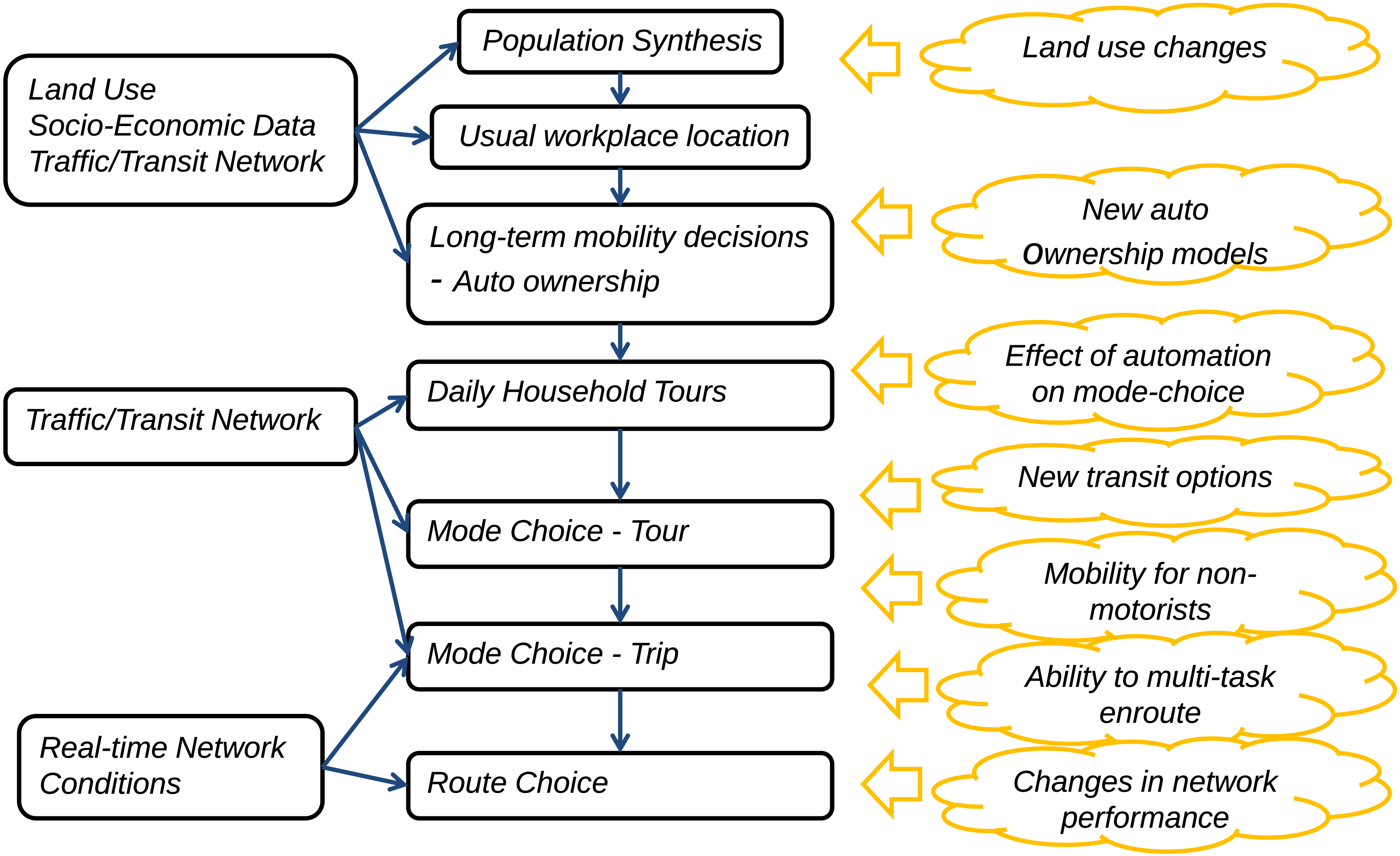
Potential Trade-offs

- In absolute terms, the inventories for NOx, PM, and energy would increase in the high-volume 100% CACC scenario
- Thought experiment: add the following number of automated vehicles for comparable results as baseline human driving:

	NOx	PM2.5	Energy
Human Baseline (vehicles/hr)	------------------------ 4976 ------------------------		
AVs to Add (vehicles/hr)	1711	1833	345

  - Uses MOVES default fleet composition in 2020
- Will induced demand for automated vehicles negate any emission and energy benefits?

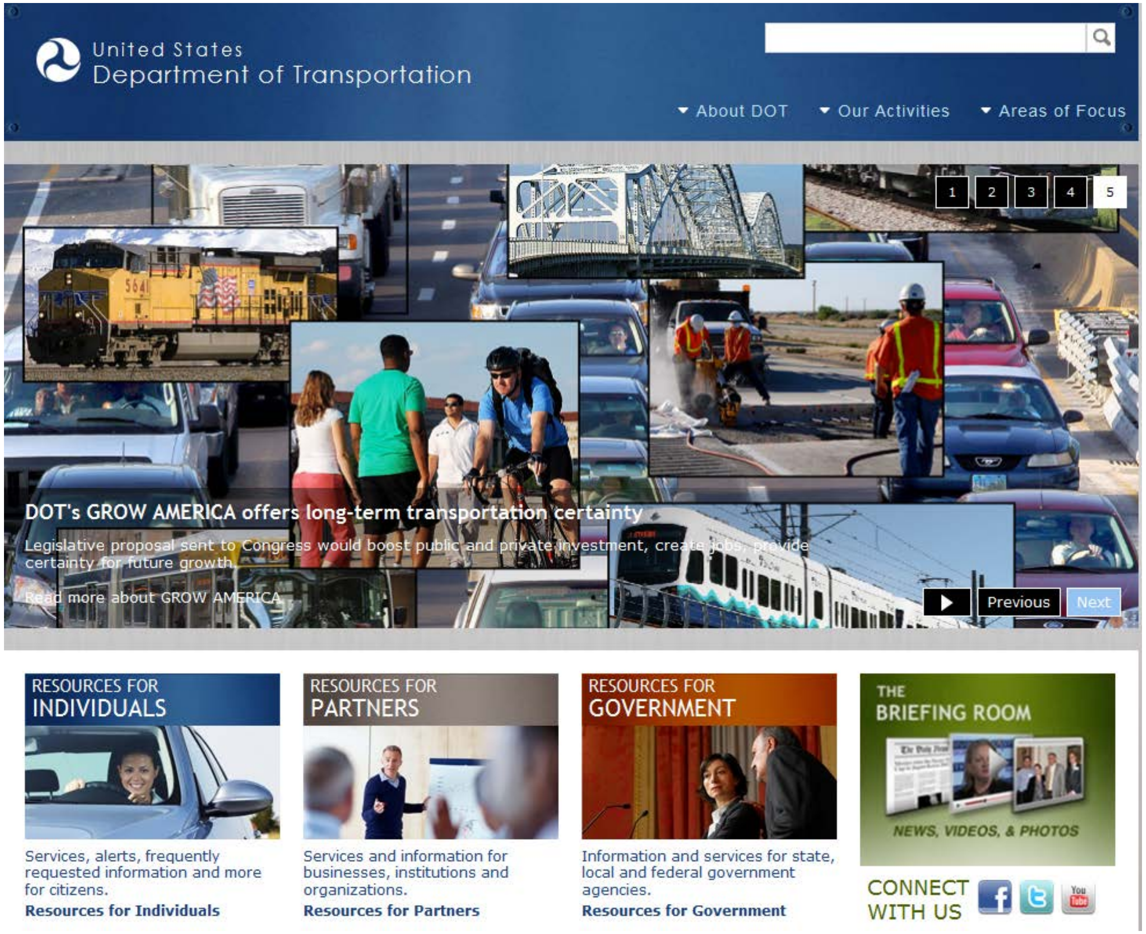
AV Effects on Travel Behavior



Next Steps

- Scale up simulations
  - Expand microsimulations to multiple links and/or road networks
- Establish modeling best practices
  - Input standardization, model fidelity, reported results
- Develop common automation scenarios
  - Use best practices to share methodology and data
- Continue discussions with DOE
  - Open to future collaboration to evaluate potential AV benefits

For More Information



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