Assessing Emissions Impacts of Automated Vehicles

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Advancing transportation innovation for the public good

U.S. Department of Transportation
Office of the Secretary of Transportation
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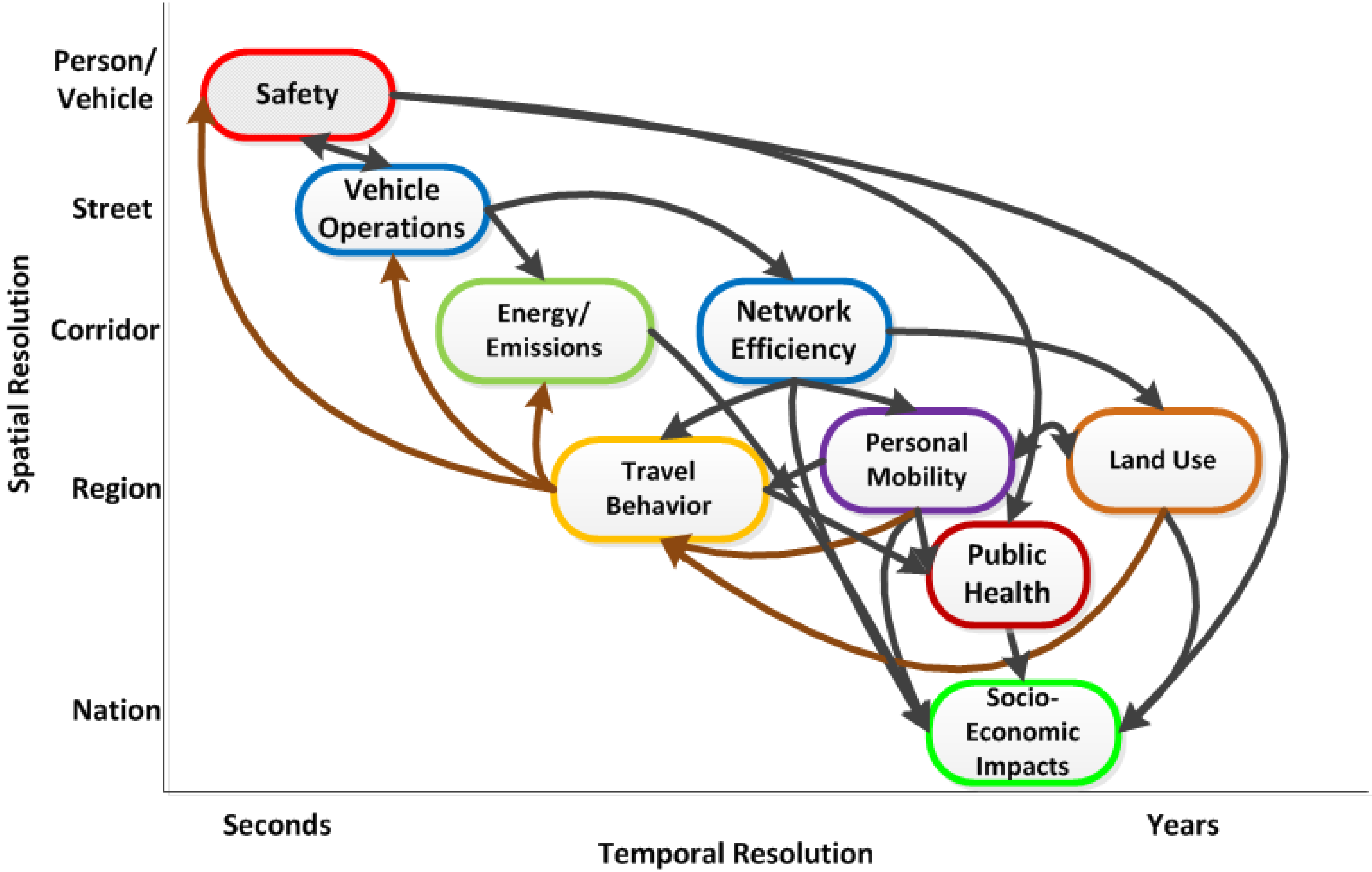
Background

- **Emissions analysis is part of 'Benefits Estimation of Automated Vehicles Operations' project being conducted by the Volpe Center**
  - Project Sponsored by FHWA Joint Program Office (JPO)
  - Project focuses on modeling several areas of vehicle automation
    - Safety
    - User Response
    - Vehicle Operations
    - **Energy / Emissions**

Background

- **Project is divided into 2 phases**
  - Phase 1, 6 months, completed in March 2016
    - White paper and prototype model of car following
  - Phase 2, 2 years
    - Add lane changes, merges and intersection gap acceptance to the model.
    - Deliver a model that a region (Metropolitan Planning Organization or city) could use to analyze the transportation system impacts of vehicles with automation applications.

Framework Elements



Related Projects

- Technical Program Management for Vehicle Automation and CV Safety
- Workzone modeling (driver behavior modeling)
- Automation field tests
  - Glidepath
  - Eco-signals – PATH / UC Riverside
  - CAMP CACC
  - Truck platooning – PATH/Caltrans
  - Truck platooning – Auburn
  - Internal Volpe CACC testing
  - Speed harmonization field tests, lane change merge
- Using Electronic Emergency Brake Light Safety Impact Methodology (EEBL SIM) Tool to estimate Prob(crash) for platooning

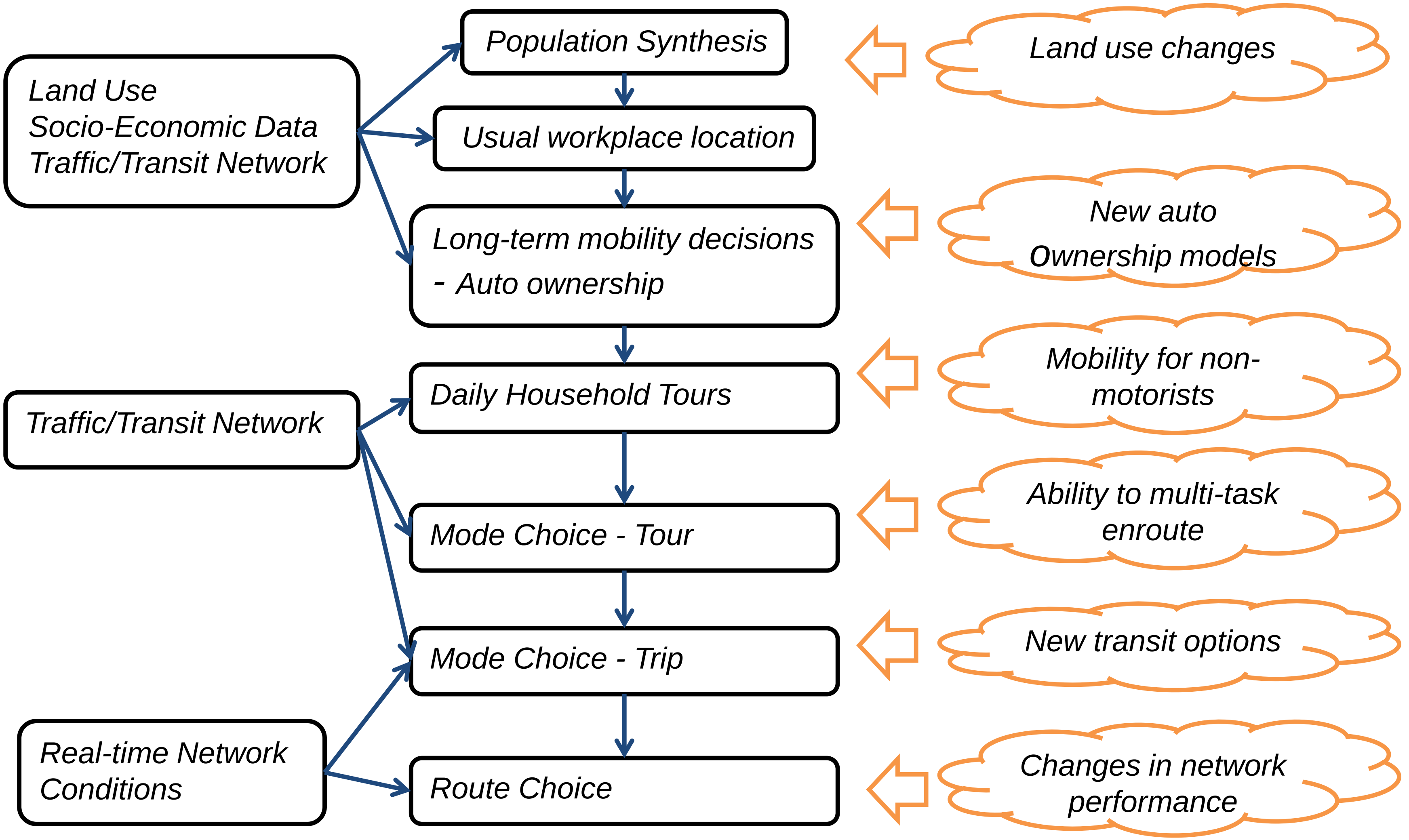
Safety

Goal: Estimate the crash avoidance effectiveness and potential safety benefits of automated vehicles

Current objectives:

1. Describe the driving conflicts on freeways experienced by passenger vehicles equipped with adaptive cruise control and crash warning applications
2. Establish a baseline of driving conflict exposure under different driving conditions (automation levels 0-1) for estimating the crash avoidance effectiveness of higher vehicle automation levels
3. Provide statistics on the availability of lane tracking information and vehicle detection during driving conflicts in different driving conditions

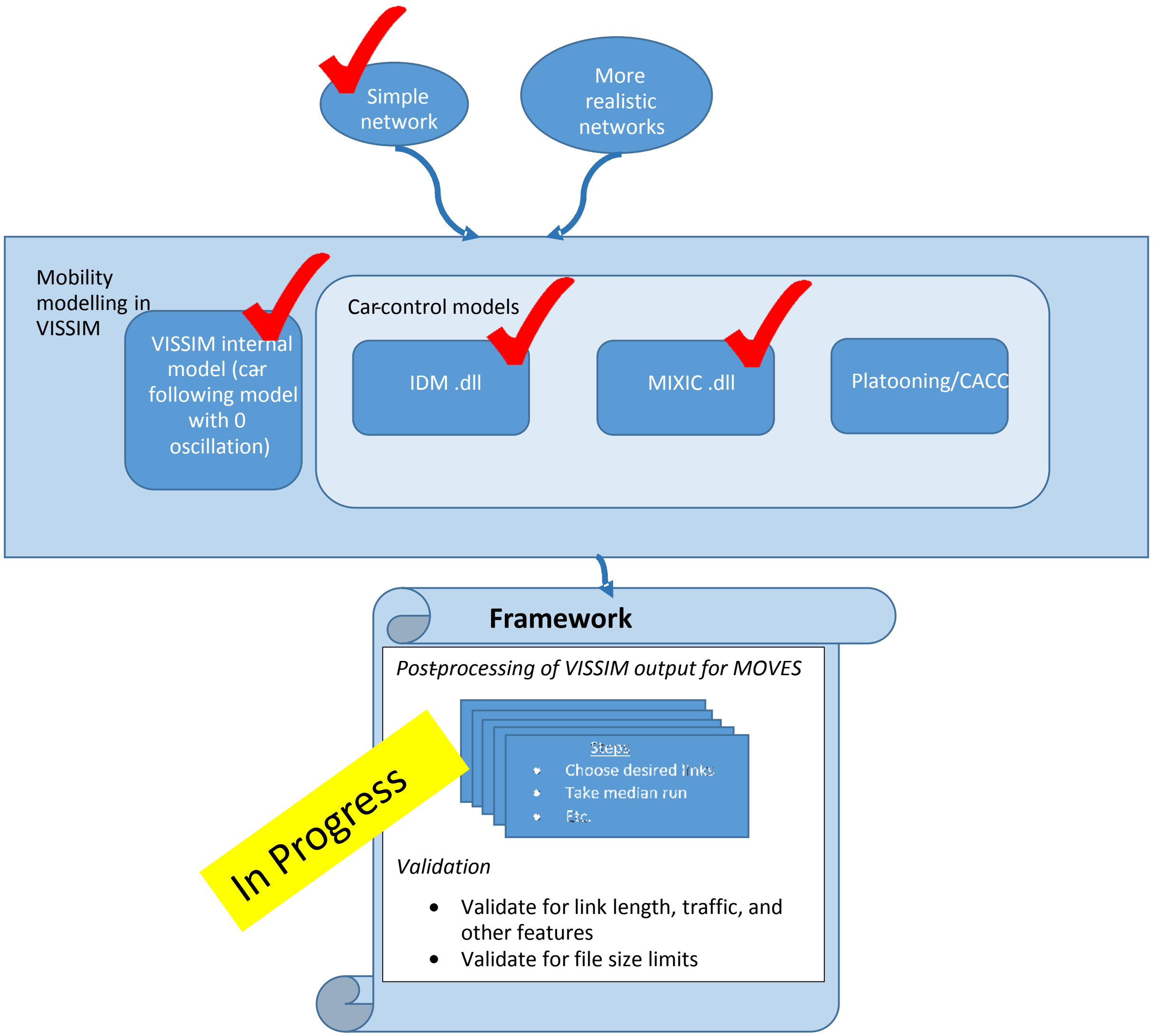
User Response
Automation in a Transportation Modeling Framework



Vehicle Operations

- Car following
  - Direct effect on lane capacity for an uninterrupted facility
  - Human driver: minimum safe headway, speed variation
  - Autonomous: less random speed variation due to driver distraction
  - Connected / automated: with real-time information from lead vehicle(s), may enable reduced headways
- Gap acceptance
  - Effect on intersection capacity
  - Human driver: depends on perception and judgment
  - Autonomous: may have less variability than humans
  - Connected / automated: possibility of cooperation with other vehicles
- Interruptions to traffic flow
  - Effect on link and intersection capacity
  - Connected / automated: possibility of cooperation with infrastructure (Glidepath), and with other vehicles to reduce interruptions

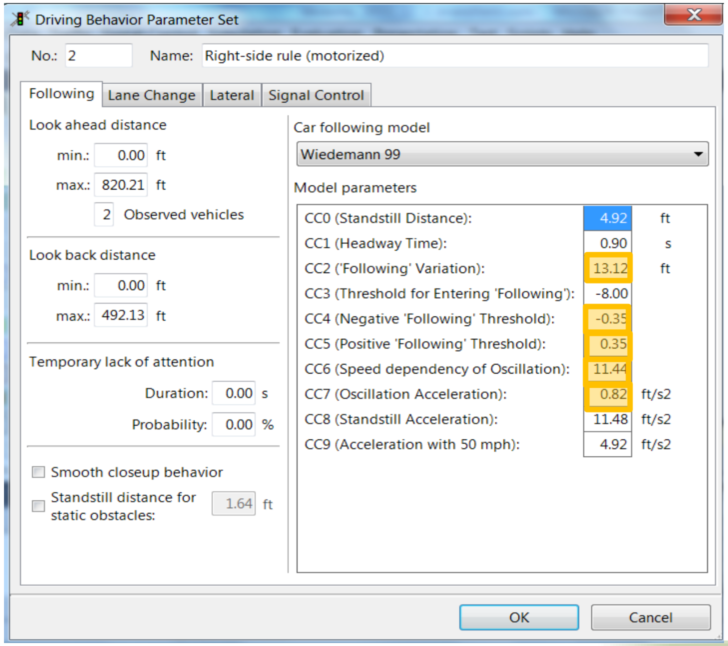
Modeling Approach

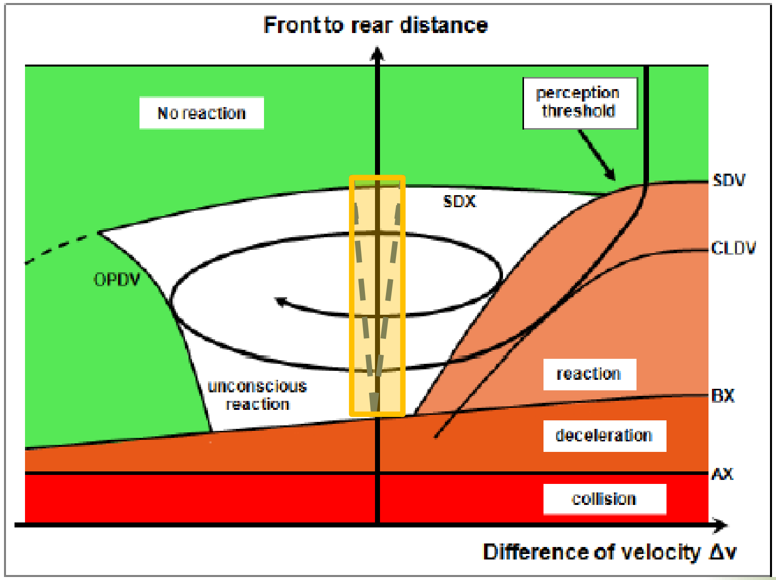


- Develop standardized road network and simulation parameters so performance of automation technology can be directly compared.
- Run simulations on externally developed .dll files to demonstrate that our framework can accommodate external inputs.
- Define a robust and repeatable process to import VISSIM data to MOVES.

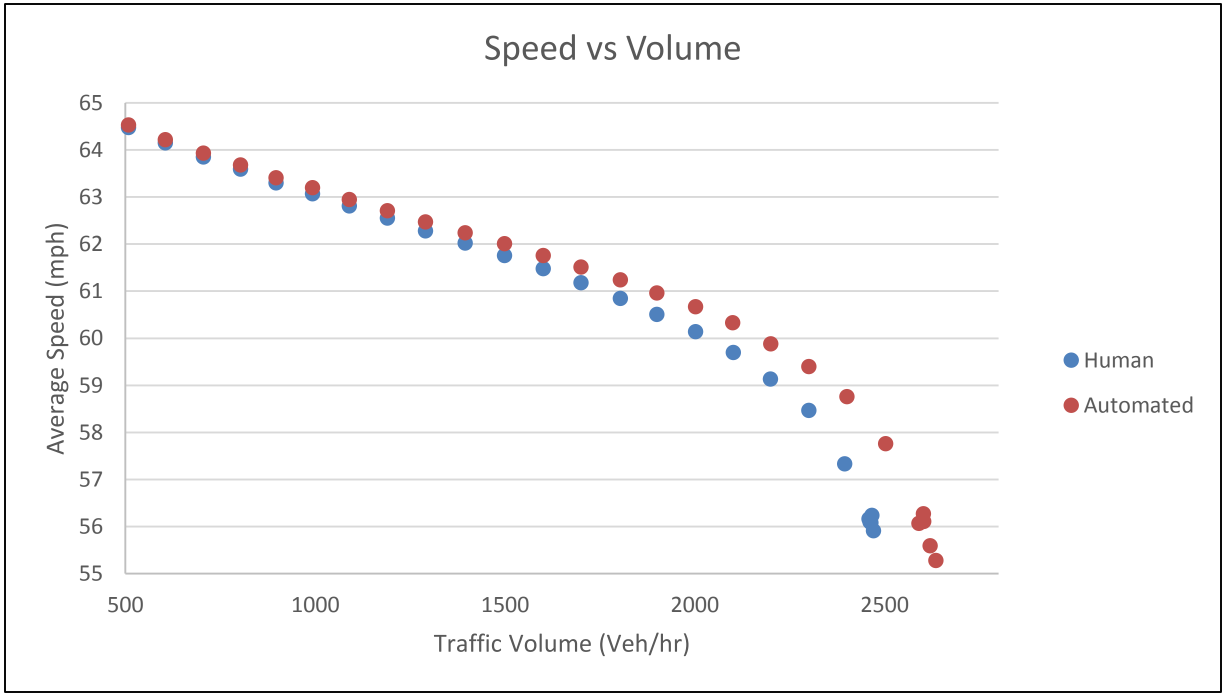
Initial Traffic Simulation Modeling

- Network and simulation parameters
  - By modifying VISSIM's car following logic, identified minimum time step and time sample ranges for evaluation purposes (10 Hz and 900-4500 sec).
  - Developed fundamental diagrams for 2 different car following approaches:
    - VISSIM's Weidemann 99 default parameters
    - Modified Weidemann 99 after removing "unconscious oscillations" – a simple ACC approximation





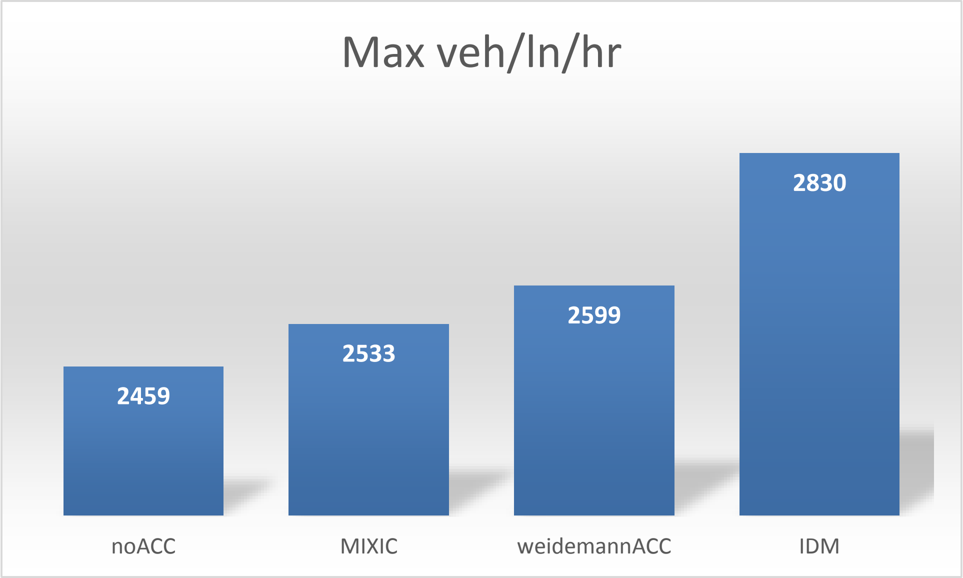
Initial Traffic Simulation Modeling Results



- One lane 2 mile long network.
- The small (~5%) improvement in capacity at 100% market penetration is consistent with prior studies.
- This data was exported to MOVES for analysis

Analysis of External Driver Models

- Have received 2 ACC .dll files from Turner Fairbank Highway Research Center.
  - MIXIC (Microscopic model for Simulation of Intelligent Cruise Control)
  - IDM (Intelligent Driver Model)
- Reviewed and summarized the source code to understand the model logic
- Ran simulations on a 3 mile long, 2 lane freeway network
- Our initial findings on the no ACC and IDM are consistent with previous findings



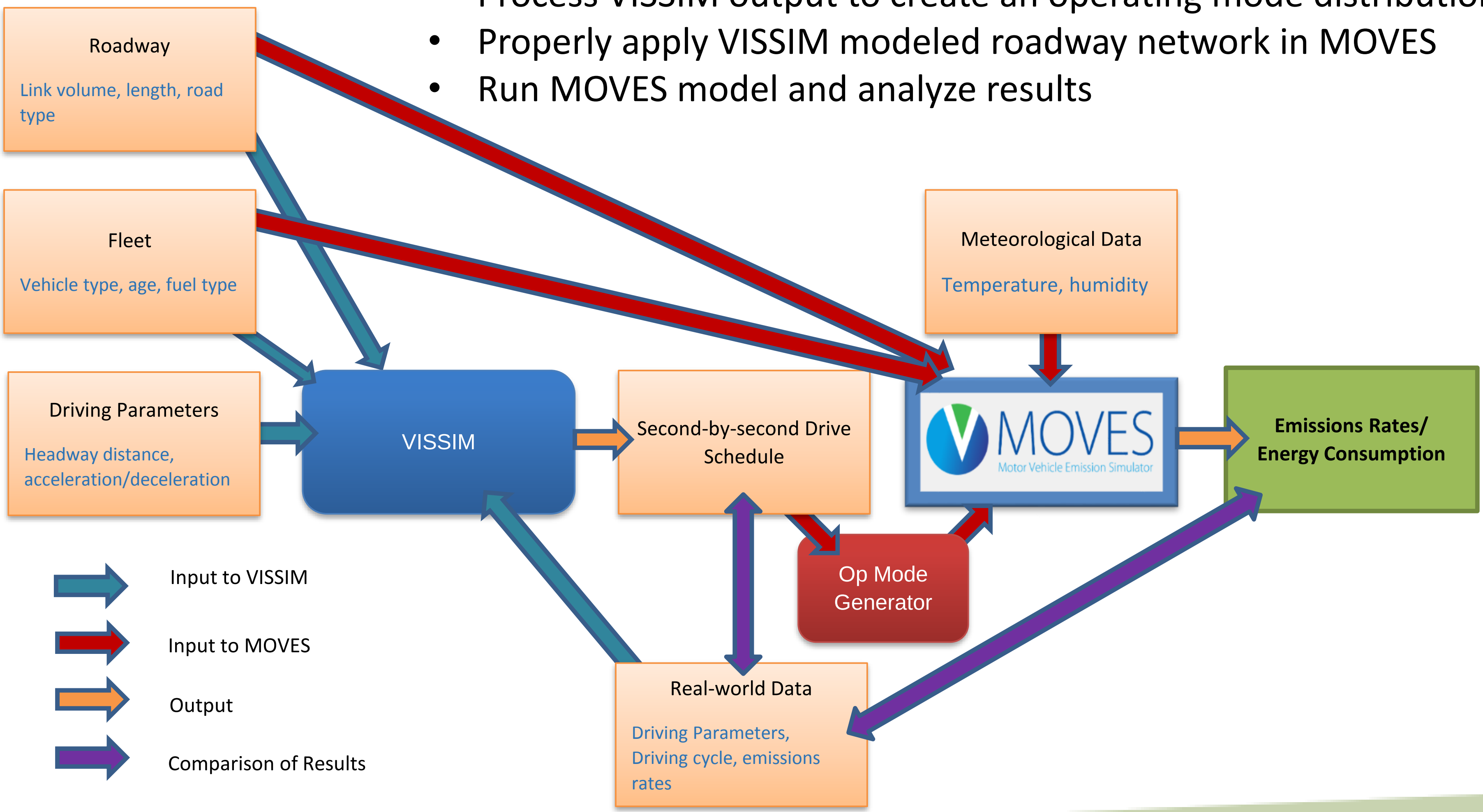
Next step is to work on the CACC model obtained developed at Turner Fairbank

Energy and Environment

- Estimate fuel consumption and emission impacts for multiple vehicle automation scenarios
  - Fuel Consumption
  - Criteria Pollutants (CO, NOx, PM_{10}, $PM_{2.5}$, and SO_2)
  - Other Pollutants (HC and VOCs)
  - GHGs (CO_2 and other greenhouse gases)
- Key Framework items for fuel and emissions modeling
  - Ability to post process vehicle operations modeling results for use with MOVES
    - Process VISSIM output into Operating Mode Distributions
  - Executing MOVES2014a with Operating Mode Distributions
    - Operating Modes are "modes" of vehicle activity that have distinct emissions rates.

Energy/Environment Approach

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



MOVES Operating Mode Distributions

- Vehicle Specific Power (VSP)

$$VSP_t = \frac{Av_t + Bv_t^2 + Cv_t^3 + mv_t a_t}{m}$$

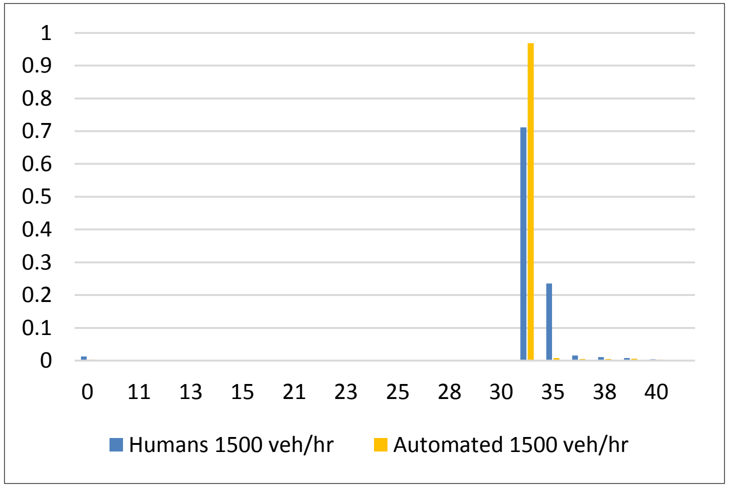
In which,
A = tire rolling resistance term (KW sec/m)
B = rotational resistance term (KW sec/m^2)
C = aerodynamic drag term (KW sec/m^3)
v_t = velocity at time, t (m/s)
a_t = acceleration at time, t (m/s^2)
m = mass (kg)

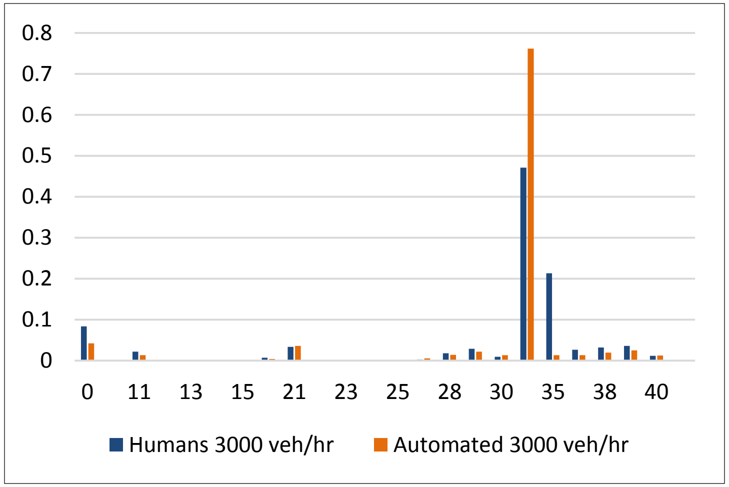
MOVES Operating Mode Distribution

Operating Mode Bin	Operation Mode Description	Vehicle-Specific Power (VSP_t, kW/metric ton)	Vehicle Speed (v_t, mph)	Vehicle Acceleration (a_t, mph/sec)
0	Deceleration/Braking			$a_t \leq -2.0$ OR ($a_t < -1.0$ AND $a_{t-1} < -1.0$ AND $a_{t-2} < -1.0$)
1	Idle		$-1.0 \leq v_t < 1.0$	
11	Coast	$VSP_t < 0$	$1 \leq v_t < 25$	
12	Cruise/Acceleration	$0 \leq VSP_t < 3$	$1 \leq v_t < 25$	
13	Cruise/Acceleration	$3 \leq VSP_t < 6$	$1 \leq v_t < 25$	
14	Cruise/Acceleration	$6 \leq VSP_t < 9$	$1 \leq v_t < 25$	
15	Cruise/Acceleration	$9 \leq VSP_t < 12$	$1 \leq v_t < 25$	
16	Cruise/Acceleration	$12 \leq VSP_t$	$1 \leq v_t < 25$	
21	Coast	$VSP_t < 0$	$25 \leq v_t < 50$	
22	Cruise/Acceleration	$0 \leq VSP_t < 3$	$25 \leq v_t < 50$	
23	Cruise/Acceleration	$3 \leq VSP_t < 6$	$25 \leq v_t < 50$	
24	Cruise/Acceleration	$6 \leq VSP_t < 9$	$25 \leq v_t < 50$	
25	Cruise/Acceleration	$9 \leq VSP_t < 12$	$25 \leq v_t < 50$	
27	Cruise/Acceleration	$12 \leq VSP_t < 18$	$25 \leq v_t < 50$	
28	Cruise/Acceleration	$18 \leq VSP_t < 24$	$25 \leq v_t < 50$	
29	Cruise/Acceleration	$24 \leq VSP_t < 30$	$25 \leq v_t < 50$	
30	Cruise/Acceleration	$30 \leq VSP_t$	$25 \leq v_t < 50$	
33	Cruise/Acceleration	$VSP_t < 6$	$50 \leq v_t$	
35	Cruise/Acceleration	$6 \leq VSP_t < 12$	$50 \leq v_t$	
37	Cruise/Acceleration	$12 \leq VSP_t < 18$	$50 \leq v_t$	
38	Cruise/Acceleration	$18 \leq VSP_t < 24$	$50 \leq v_t$	
39	Cruise/Acceleration	$24 \leq VSP_t < 30$	$50 \leq v_t$	
40	Cruise/Acceleration	$30 \leq VSP_t$	$50 \leq v_t$	

Initial Emissions Modeling

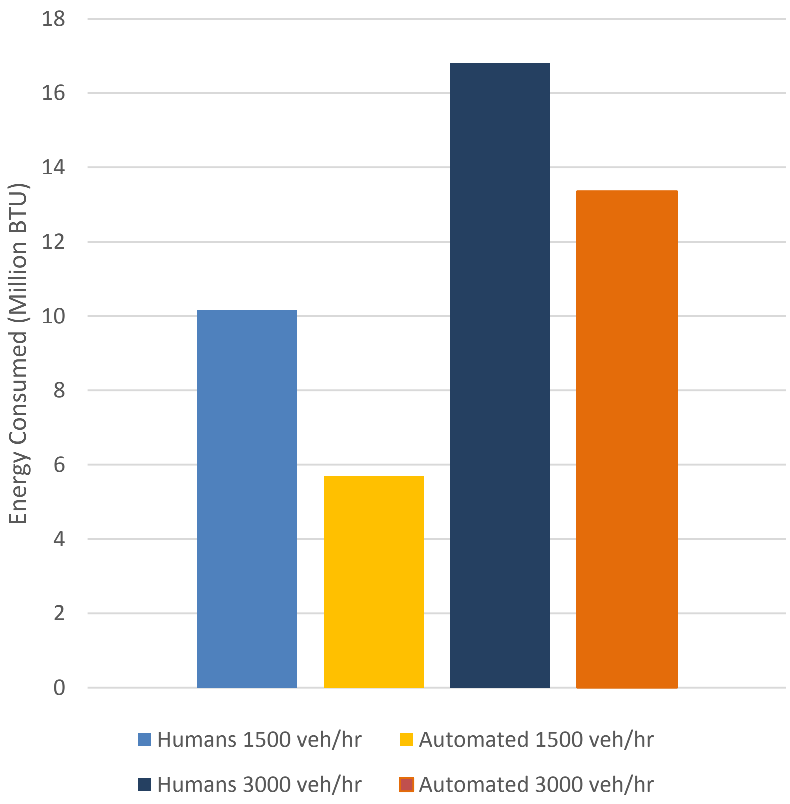
- Developed a MATLAB script for creating operating mode distribution from VISSIM output
- Simple Scenario: Fully automated vs. Non-automated at two capacities
- Operating Mode Distributions from Simple Scenario:



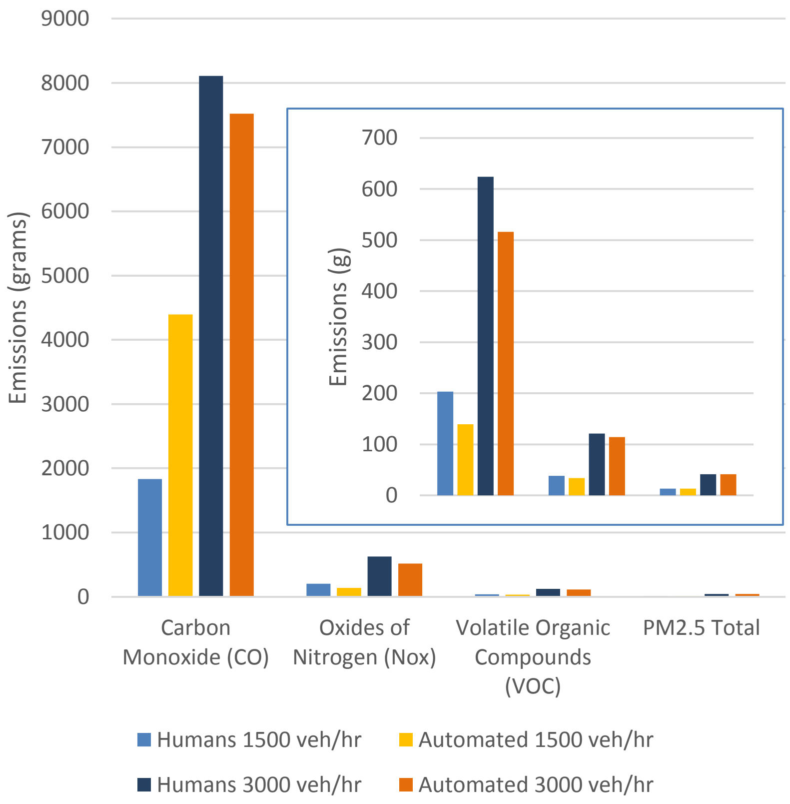


Initial Emission Modeling Results

Energy Consumption



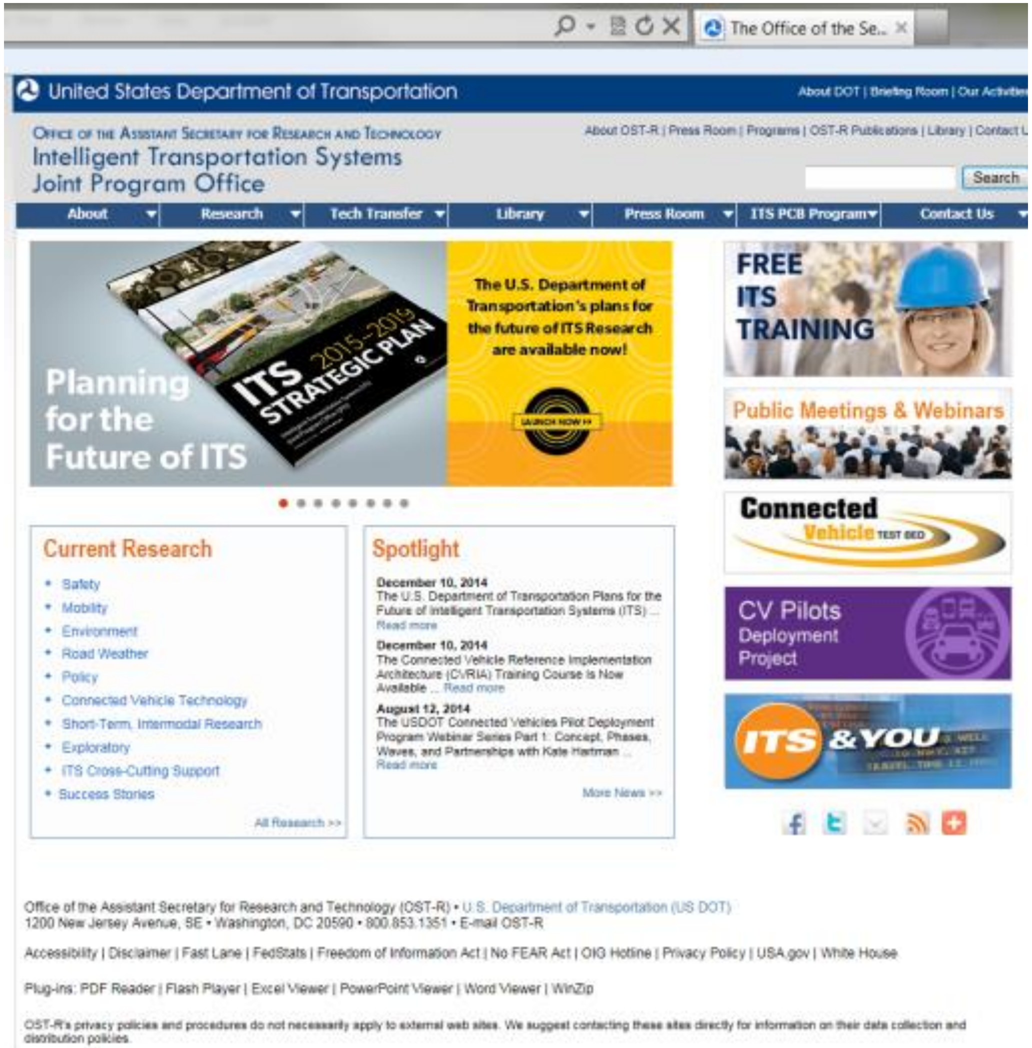
Emissions



Next Steps

- Scaling up the methodology for more complex scenarios
  - Utilize Python and SQL to handle larger datasets
- As we create a framework for more complex systems, it is critical to specify how to appropriately model a microsimulation layout with MOVES
- Will need to manipulate MOVES VSP parameters
  - Aerodynamic Drag
- Develop scenarios that incorporate other emissions processes
  - Vehicle starts
  - Hotelling and APU Usage

For More Information



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Thank You!

Questions?

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