A framework for evaluating energy and emissions of connected and automated vehicles through traffic microsimulations

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INTRODUCTION

Connected and automated vehicles (CAV) are poised to transform surface transportation systems in the United States. Near-term CAV technologies like cooperative adaptive cruise control (CACC) have the potential to deliver energy efficiency and air quality benefits. This poster lays out a modeling framework for evaluating energy and tailpipe emission impacts from vehicle automation and connectivity, including an initial case study of passenger cars on Interstate 91 (I-91) northbound near Springfield, Massachusetts.

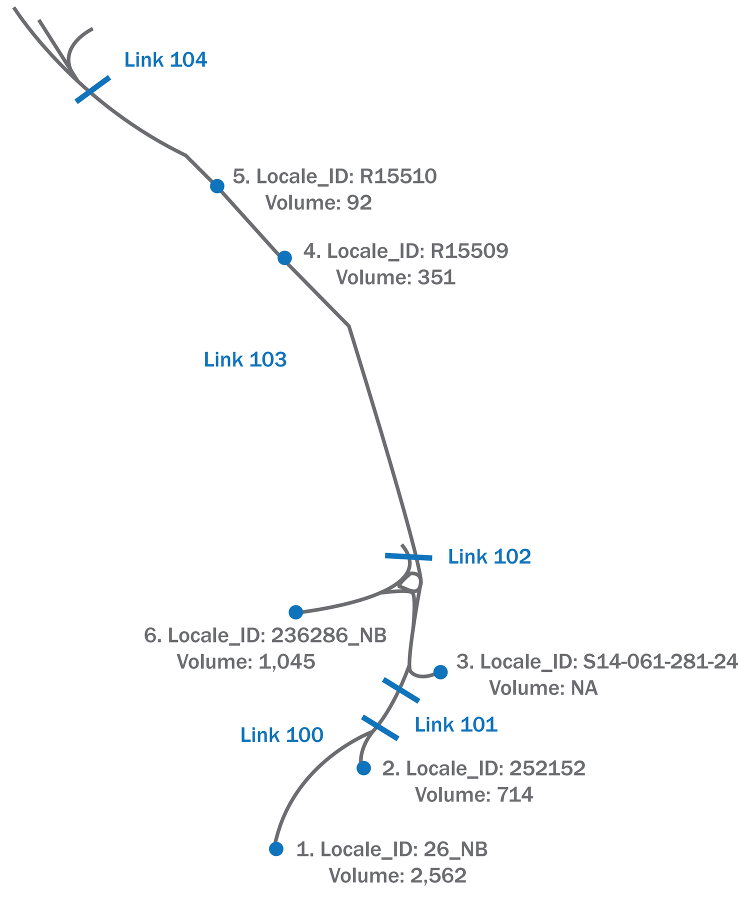

Figure 1 Microsimulation network of Interstate 91 northbound near Springfield, MA with observed weekday morning traffic volumes (1-6) and numbered links (100-104)

SCENARIOS

We devised three scenarios with varied driving behavior:

1. Baseline driving behavior with Vissim's default Wiedemann 99 car following;
2. CACC driving behavior using an adjusted MIXIC model car following model; and
3. Modified Wiedemann 99 car following where oscillation parameters have been set to zero.

The CACC MIXIC model used in the second scenario was adapted from work for the Federal Highway Administration's Turner-Fairbank Highway Research Center, such that flags for platooning, lane change, and a designated lane were turned off. In the third scenario, the following five Wiedemann 99 parameters were set to zero and expected to smooth driving behavior: following variation (CC2), negative following threshold (CC4), positive following threshold (CC5), speed dependency of oscillation (CC6), and oscillation acceleration (CC7).

FRAMEWORK & METHODS

This research proposes a three-layered modeling framework that combines the following tools to estimate the energy consumption and tailpipe emission impacts of connected and automated vehicles:

Driving behavior model for specific CAV technologies

Microscopic traffic simulation model

Modal emissions model

In a case study to test this framework, we utilized the software and data highlighted below:

- The microscopic model for simulation of intelligent cruise control (MIXIC) to represent CACC driving,
- PTV Vissim, traffic microsimulation software, for modeling the I-91 network in Figure 1,
- Real-world traffic speeds and volumes from a Massachusetts Department of Transportation dataset,
- High-resolution (10 hertz), simulated car trajectories processed into operating modes by time spent, and
- The Motor Vehicle Emission Simulator (MOVES) for hourly project-scale emissions and energy use.

MOVES assigns each time step *t* of a vehicle trajectory into one of 23 operating modes through binning of three time-dependent variables: vehicle-specific power (VSP_t), vehicle speed (v_t), and vehicle acceleration (a_t). *VSP* is the tractive power to propel the vehicle normalized by its mass *m*, as defined with the road load coefficients *A*, *B*, and *C* below:

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

NETWORK PERFORMANCE

We found that the second scenario with CACC driving does not increase average vehicle speeds much over the baseline scenario except for Link 101, but it will narrow the range of speeds, particularly for links with higher congestion, as shown in Figure 2. The third scenario where the Wiedemann 99 oscillation parameters are set to zero does not show appreciable difference in speeds from the baseline. Similar analysis was performed for vehicle acceleration, delay, and headway. For higher confidence, each scenario was run over 15 random seeds.

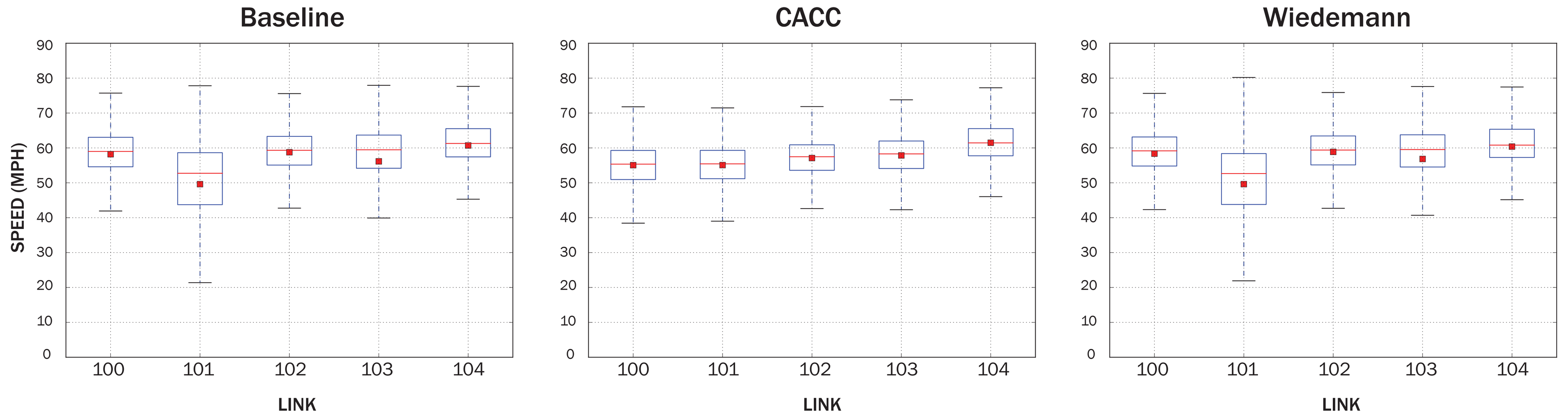

Figure 2 Box plots of vehicle speed (miles per hour) for the first random seed as an example on the I-91 network by link and scenario (red dot represents the mean)

OPERATING MODE DISTRIBUTIONS

Despite modest changes to network performance metrics, especially delay and headway, CACC systems produce substantial changes to operating mode distributions and subsequent emissions from the baseline. For Link 101 in Figure 3, the CACC scenario shows large drops in braking (op mode 0) and op mode 30 (25-50 mph, high VSP) from the baseline while the Wiedemann scenario has higher fractions in op modes 30 and 40 (50+ mph, highest VSP).

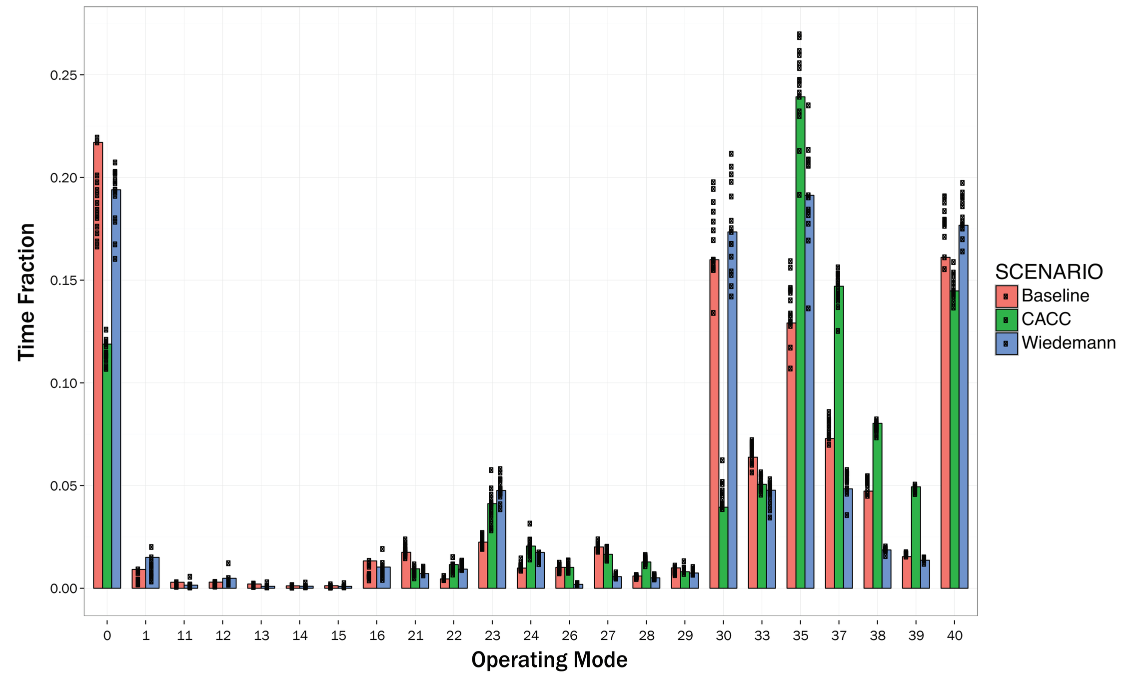

Figure 3 Operating mode distributions for Link 101 of the I-91 network (bar represents the first random seed and points represent the other 14 seeds)

ENERGY & EMISSION IMPACTS

Pollutant Reduction	CACC from Baseline		Wiedemann from Baseline	
	Mean	Std. Dev.	Mean	Std. Dev.
CO	20.12%	±3.85%	-0.84%	±6.64%
NOx	2.53%	±2.20%	1.59%	±3.21%
PM2.5	25.24%	±4.05%	-3.35%	±7.55%
VOC	10.41%	±2.89%	1.71%	±4.61%
Energy/CO_2	-0.23%	±1.38%	0.25%	±1.97%

Table 1 Mean percent reduction and standard deviation by pollutant on the I-91 network for the CACC and Weidemann scenarios from the baseline over the 15 random seeds

Pairing the energy and emission results by seed, Table 1 above shows the mean percent reductions and standard deviations for the CACC and Wiedemann without oscillations scenarios for carbon monoxide (CO), nitrogen oxides (NOx), fine particulate matter (PM2.5), volatile organic compounds (VOC), carbon dioxide (CO_2), and energy use.

Our findings suggest that CACC driving on the I-91 network will lead to sizable CO, PM, and VOC benefits along with slight NOx benefits but will not improve fuel efficiency over the baseline. The Wiedemann scenario, however, leads to negligible or no benefits from the baseline. Our future research will study higher traffic volumes and mixed traffic scenarios.

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FOR MORE INFORMATION
See TRB Paper 18-06134 at amonline.trb.org, visit its.dot.gov, or contact Andrew Eilbert (andrew.eilbert@dot.gov).

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