Finding the tipping point: a sensitivity analysis of network performance and environmental benefits of cooperative adaptive cruise control in freeway driving

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INTRODUCTION

Vehicle automation is expected to improve the ease and accessibility of personal vehicle travel; some predict this could induce travel, although connected and automated vehicle (CAV) driving systems such as cooperative adaptive cruise control (CACC) are expected to increase freeway capacity, improve fuel efficiency, and reduce tailpipe emissions. The US Department of Transportation developed the Automated Vehicle Benefits (AVB) framework to better predict the impacts of CAVs.

EVALUATION FRAMEWORK

This study builds upon earlier work for the AVB framework that proposed a three-layered modeling approach for evaluating CAV driving systems. It layers 1) the microscopic model for simulation of intelligent cruise control (MIC0X), 2) PTV Visum for traffic microsimulations, and 3) the Motor Vehicle Emission Simulator (MOVES) at project scale. Despite tight model integration, this sequential approach is highly sensitive to parametric design and input data, as highlighted in Figure 1 below.

CASE STUDY

In a case study of a 4-mile freeway segment on Interstate 91 (I-91) near Springfield, Massachusetts, we compared passenger vehicles using CACC longitudinal control systems against baseline approaches for evaluating CAV driving systems. It layers 1) the microscopic model for simulation of intelligent cruise control (MIC0X), 2) PTV Visum for traffic microsimulations, and 3) the Motor Vehicle Emission Simulator (MOVES) at project scale. Despite tight model integration, this sequential approach is highly sensitive to parametric design and input data, as highlighted in Figure 1 below.

SENSITIVITY ANALYSIS

To test the operational and environmental sensitivities of the I-91 network, we varied traffic volumes and CACC technology penetrations. The following cases were considered:

- Four traffic volume cases: the base observed volumes (weekend morning peak period), multiplied by 1.0, 1.2, 1.4, and 1.6.
- Three CACC technology penetrations: 0% CACC (baseline), 50% CACC, and 100% CACC. In the 50% CACC scenario, CACC-equipped vehicles following non-equipped vehicles revert to adaptive cruise control (ACC) behavior, and each vehicle-penetration pairing was run 5 times for 4500 seconds, with 900 seconds for warm up, and results reported for the final 3600 seconds.

ROAD GEOMETRY & DESIGN

Figure 2 shows the I-91 limited access network near Springfield, which includes five links (100-104) and six traffic entry points (1-6).

NETWORK PERFORMANCE

Traffic density was computed by dividing the flow over the average speed for each link. Figure 4 below shows the fundamental traffic flow diagrams for two links (100 and 103) on the I-91 Springfield network. Link 100 is a particular good illustration of the parabolic traffic flow-density curves and all scenarios have high goodness-of-fit values (R² is greater than 0.93) for second-order polynomial fitted curves and 95% confidence bands.

ENVIRONMENTAL BENEFITS

On a network level, increased I-91 volumes often led to per-vehicle fuel efficiency gains. The following cases were considered:

- 1.0 CACC rate is not visible.
- 1.2 -20% -11% -5% +1% +9%
- 1.4 -21% -16% -16% -11% -11%
- 1.6 -21% -17% -12% -9% -9%

Our results indicate high sensitivity to network design and road geometry and moderate sensitivity to traffic volumes and CACC penetrations. Further research with other networks and other CACC models can confirm the operational and environmental benefits found in this freeway study.

AS A RESULT OF THE WORK

- Our results indicate high sensitivity to network design and road geometry and moderate sensitivity to traffic volumes and CACC penetrations.
- Further research with other networks and other CACC models can confirm the operational and environmental benefits found in this freeway study.

FOR MORE INFORMATION

See our AVB Report Online: https://rosap.ntl.bts.gov/view/dot/34458, visit its.dot.gov or contact Andrew Elbert [andrew.elbert@its.dot.gov].

Table 2. I-91 network-level PM2.5 reductions and fuel savings per vehicle for 50% and 100% CACC scenarios against the baseline

<table>
<thead>
<tr>
<th>Scenario</th>
<th>50% CACC</th>
<th>100% CACC</th>
</tr>
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<tbody>
<tr>
<td>Volumechange</td>
<td>+4%</td>
<td>+6%</td>
</tr>
<tr>
<td>ChangeinPM2.5</td>
<td>-11%</td>
<td>-9%</td>
</tr>
<tr>
<td>ChangeinFuel</td>
<td>-5%</td>
<td>+1%</td>
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</table>