Freeway Capacity in a Connected/Automated Mixed Traffic Environment

Sarah El-Dabaja\textsuperscript{1}, Bhaven Naik\textsuperscript{2}, Deborah McAvoy\textsuperscript{3}

\textsuperscript{1}Ph.D. Candidate, Ohio University, 037 Stocker Center, 1 Ohio University, Athens, OH, 45701, Email: se954207@ohio.edu

\textsuperscript{2}Assistant Professor, Ohio University, 226 Stocker Center, 1 Ohio University, Athens, OH 45701, Email: naik@ohio.edu

\textsuperscript{3}Associate Professor, Ohio University, 122 Stocker Center, 1 Ohio University, Athens, OH 45701, Email: mcavoy@ohio.edu
Discussion Topics

- The Move Towards CACC
- CACC and Freeway Capacity
- Research Objectives
- Proposed Methodology
- Anticipated Results and Implications
The Problem: Congestion

6.9 billion hours lost

3.1 billion gallons of fuel wasted

$160 billion spent

One Potential Solution: CACC

- **Judgement, reaction times, execution**
- **Traffic Flow Stability**
  - Harmonious environment
- **Tighter Platoons**
  - Compact clusters
- **Increased Capacity**
  - More efficient movement of more vehicles
- **Reduced Variability**

The best student-centered learning experience in America
CACC on Freeways
Platooning Algorithms

- Vehicles coupled wirelessly to form dense road trains

[2]

CACC on Freeways
Platooning Algorithms

- Relies on some form of gap regulation

- Enhances capacity through string stability and shorter headways

CACC on Freeways
Merging Algorithms

- Encourages gap creation for smooth transitions and easy accelerations and decelerations

CACC on Freeways
Merging Algorithms

• Variety of techniques
  – Control merging vehicle, mainline vehicles, or both
  – Virtual gap creation
  – Slot-based
  – Ideal driver behavior
  – Mathematical optimization

• Enhances capacity by reducing conflicts\(^5\)

---

## CACC Freeway Capacity Estimates

<table>
<thead>
<tr>
<th>Penetration Rate (%)</th>
<th>Base Capacity (vph)</th>
<th>CACC Capacity (vph)</th>
<th>Percent Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2,020</td>
<td>2,050</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>2,020</td>
<td>2,100</td>
<td>4</td>
</tr>
<tr>
<td>20</td>
<td>4,900</td>
<td>5,000</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>4,890</td>
<td>5,000</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5,300 w/lane</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>6,000</td>
<td>6,000</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8,300 w/lane</td>
<td>38</td>
</tr>
<tr>
<td>20</td>
<td>8,100</td>
<td>8,150</td>
<td>0.6</td>
</tr>
<tr>
<td>30</td>
<td>2,020</td>
<td>2,150</td>
<td>6</td>
</tr>
</tbody>
</table>

---


### CACC Freeway Capacity Estimates

<table>
<thead>
<tr>
<th>Penetration Rate (%)</th>
<th>Base Capacity (vph)</th>
<th>CACC Capacity (vph)</th>
<th>Percent Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>2,020</td>
<td>2,250</td>
<td>11</td>
</tr>
<tr>
<td>40</td>
<td>4,900</td>
<td>5,500</td>
<td>12</td>
</tr>
<tr>
<td>40</td>
<td>8,100</td>
<td>8,200 7,990 w/lane</td>
<td>1 -1.4</td>
</tr>
<tr>
<td>50</td>
<td>2,020</td>
<td>2,300</td>
<td>14</td>
</tr>
<tr>
<td>60</td>
<td>2,020</td>
<td>2,600</td>
<td>29</td>
</tr>
<tr>
<td>60</td>
<td>4,900</td>
<td>6,000</td>
<td>22</td>
</tr>
<tr>
<td>60</td>
<td>8,100</td>
<td>8,300 8,300 w/lane</td>
<td>2.5 2.5</td>
</tr>
<tr>
<td>70</td>
<td>2,020</td>
<td>2,700</td>
<td>34</td>
</tr>
</tbody>
</table>

---


<table>
<thead>
<tr>
<th>Penetration Rate (%)</th>
<th>Base Capacity (vph)</th>
<th>CACC Capacity (vph)</th>
<th>Percent Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>2,020</td>
<td>2,900</td>
<td>44</td>
</tr>
<tr>
<td>80</td>
<td>4,900</td>
<td>7,450</td>
<td>52</td>
</tr>
<tr>
<td>80</td>
<td>8,100</td>
<td>8,300</td>
<td>2.5</td>
</tr>
<tr>
<td>90</td>
<td>2,020</td>
<td>3,300</td>
<td>63</td>
</tr>
<tr>
<td>100</td>
<td>600</td>
<td>3,250</td>
<td>442</td>
</tr>
<tr>
<td>100</td>
<td>1,540</td>
<td>1,880</td>
<td>22</td>
</tr>
<tr>
<td>100</td>
<td>2,020</td>
<td>4,000</td>
<td>98</td>
</tr>
<tr>
<td>100</td>
<td>8,100</td>
<td>8,300</td>
<td>2.5</td>
</tr>
<tr>
<td>100</td>
<td>4,900</td>
<td>7,800</td>
<td>59</td>
</tr>
</tbody>
</table>

Problems with Current Estimates

• Major discrepancies in estimates
• Inconsistencies in methodology
  – No single approach for practitioners to apply like HCM
• Uncertainties related to manual driver behavior in a mixed traffic environment
  – What headway will drivers choose?
  – Will reaction times be affected?
Research Objectives

• Investigate manual driver behavior in a mixed traffic environment under varying penetration rates

• Derive traffic flow parameters that are statistically significant and generalizable:
  – PRTs
  – Headways
  – PCEs of CACC vehicles (passenger cars, heavy trucks, buses, RVs)

• Develop new freeway capacity analysis method in consideration of varying penetration rates
Proposed Methodology

Phase I: Driving Simulation

Phase II: Microsimulation

Phase III: Synthesis of Results into Capacity Analysis Method
Phase I – Driving Simulation

- **Purpose**: To obtain critical values of PRTs and headways for manual vehicles
- **DriveSafety driving simulator**
- **Research Tasks**:
  - Develop freeway driving scenarios
  - Recruit participants
  - Collect and analyze data
Phase I – Driving Simulation

Inputs
- Ambient traffic control
- Subject vehicle control
- Environment
- Event triggers

Outputs
- Acceleration
- Braking
- Headways
- Gaze
- Heart Rate
- PRTs
Driver Behavior Research in Progress

- Driver reaction to failure of fully autonomous system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Immediate Response</th>
<th>Long-Term Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane Position</td>
<td>Lane departure</td>
<td>More oscillation, lane departures</td>
</tr>
<tr>
<td>Steering</td>
<td>“Jerky” right to left</td>
<td>Less controlled</td>
</tr>
<tr>
<td>Velocity</td>
<td>Decreases approximately 10-15 mph</td>
<td>±10-25 mph deviations from speed limit</td>
</tr>
<tr>
<td>Acceleration</td>
<td>Drops, then fully depressed</td>
<td>Harder accelerations</td>
</tr>
<tr>
<td>Braking</td>
<td>Not applied</td>
<td>Harder braking</td>
</tr>
</tbody>
</table>
Phase II - Microsimulation

• Purpose: To observe impacts of new traffic parameter values on flow and capacity
• VISSIM package
• Research Tasks:
  – Develop model calibrated with driving simulator data
  – Conduct sensitivity analysis of capacity impacts related to CACC penetration rates
Phase III – Synthesis of Results into Capacity Analysis Method

• Purpose: To develop uniform and applicable methods for calculating freeway capacity estimates with CACC

• Research Tasks:
  – Statistical modeling to develop analysis techniques similar to HCM methods
Anticipated Results and Implications

• Phase I
  – PRTs, headways, and PCEs corresponding to penetration rates
  – Replace subjective assumptions with substantive empirical values

• Phase II
  – Fully calibrated microsimulation model
  – Analysis of CACC algorithms (e.g., platooning, merging)

• Phase III
  – Freeway capacity analysis methods for mixed traffic environment
  – Consistent estimates of freeway capacity with CACC
Questions?

Create for Good.

Thank you!

THE RUSS COLLEGE OF ENGINEERING AND TECHNOLOGY

Ohio University
References


Photo Credits

http://careerconfidential.com/i-wasted-time-job-boards/
http://www.alexsworld.co/what-does-the-nd-mean-for-me/
http://www.aopa.org/Pilot-Resources/Aircraft-Ownership/The-Pilots-Guide-to-Taxes/
http://www.ohio.edu/research/communications/driving_simulation.cfm