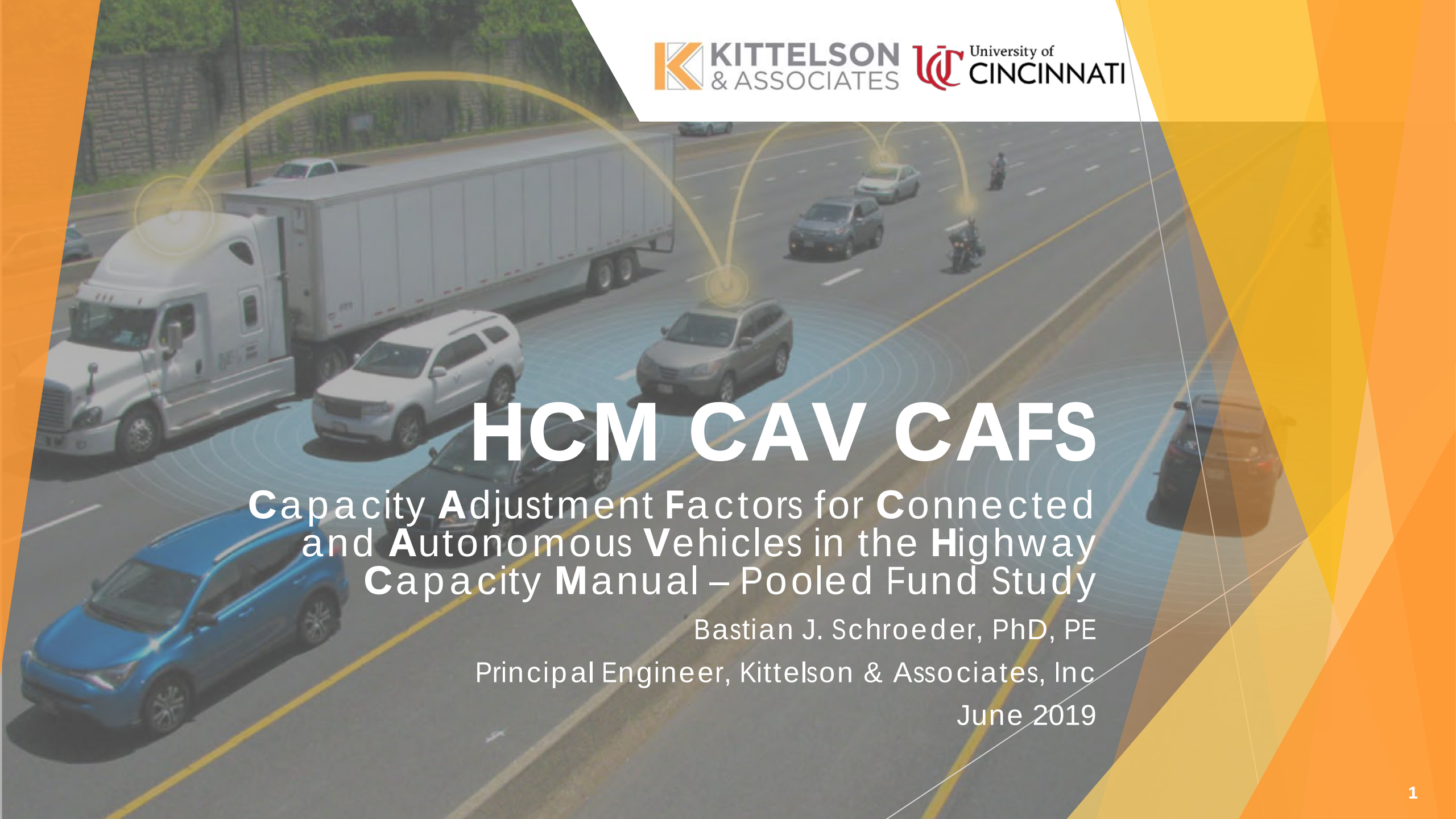

HCM CAV CAFS

Capacity **A**djustment **F**actors for **C**onnected and **A**utonomous **V**ehicles in the **H**ighway **C**apacity **M**anual – Pooled Fund Study

Bastian J. Schroeder, PhD, PE

Principal Engineer, Kittelson & Associates, Inc

June 2019

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  - **Brian Dunn, Oregon DOT**
  - **Tony Knudson, Oregon DOT**
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  - Kittelson and Associates
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    - Anxi Jia
    - Lake Trask
    - Alicia Hunter
  - University of Cincinnati
    - Jiaqi Ma

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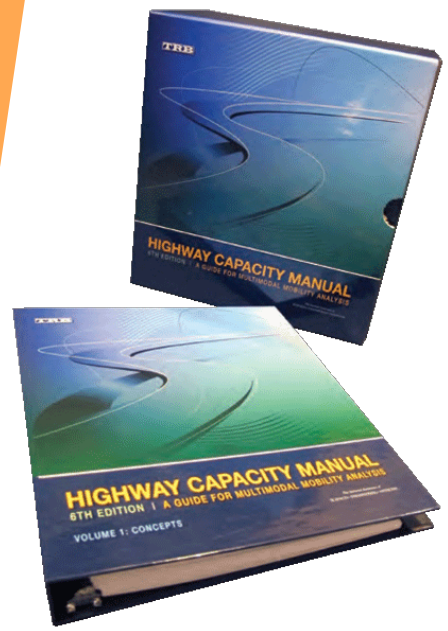
POOLED FUND STUDY OVERVIEW



Objectives:

Develop highway capacity adjustments for CAVs at different levels of volume and market penetration

Agent-Based Approach:

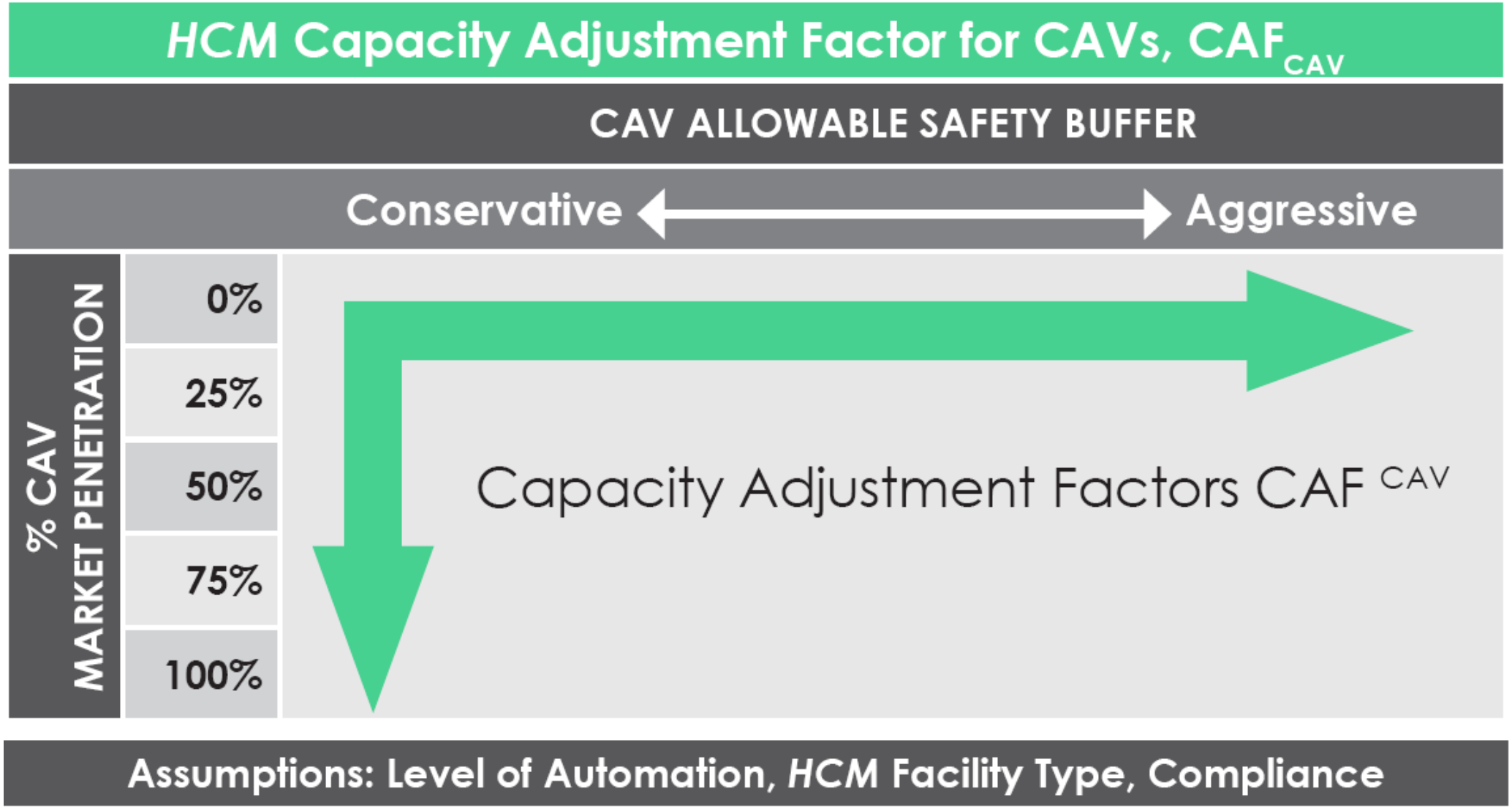
Vehicle and driver behavior fully customizable for simulation scenarios

Project Milestones

Freeway Models (Spring 2019)

Intersection Models (Fall 2019)

Arterial Models (Spring 2020)


HCM Capacity Adjustment Factor for CAVs, CAF CAV
CAV ALLOWABLE SAFETY BUFFER
Conservative
Aggressive
% CAV MARKET PENETRATION
0%
25%
50%
75%
100%
Capacity Adjustment Factors CAF CAV
Assumptions: Level of Automation, HCM Facility Type, Compliance

AV – CV - CAV

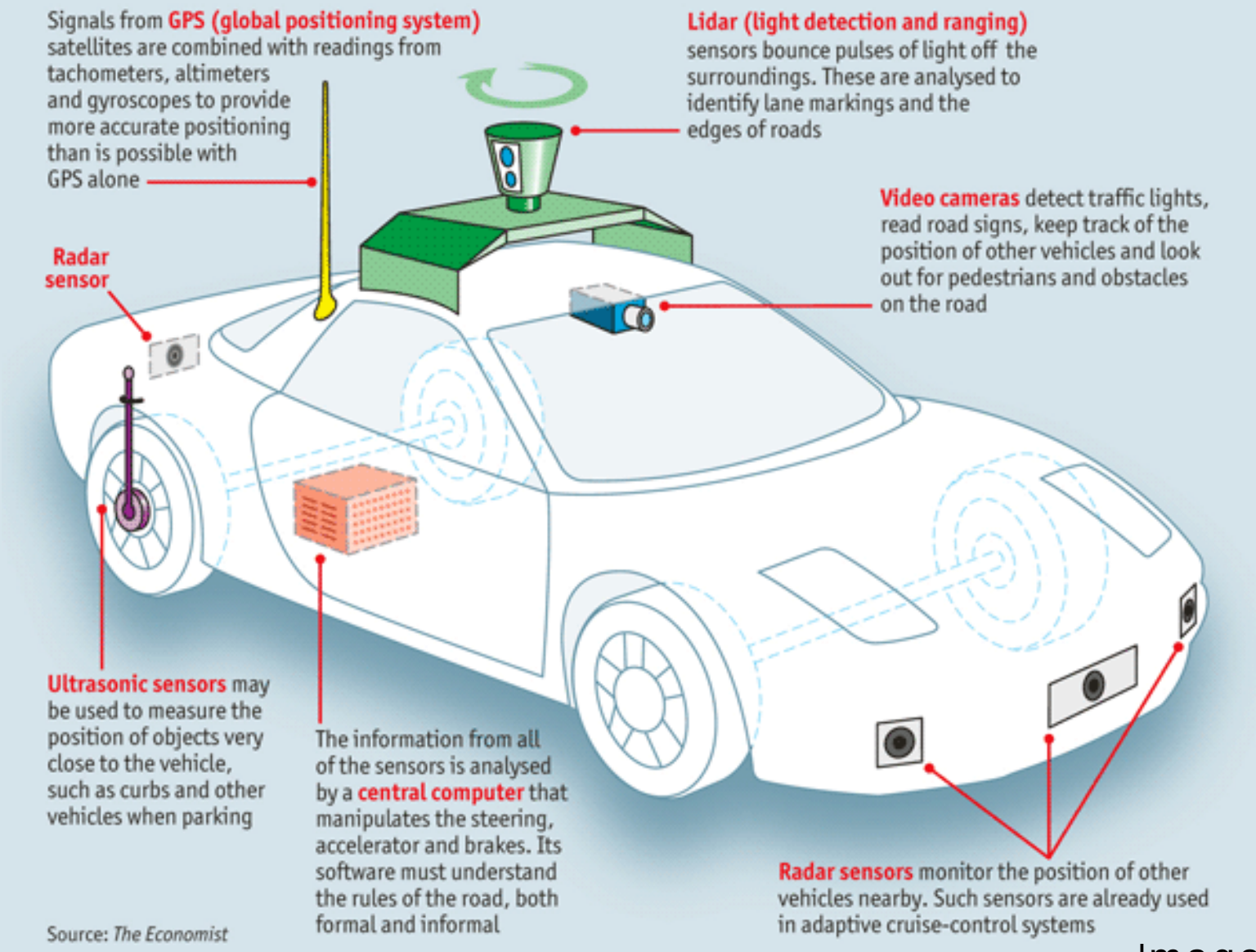


Image Credit: The Economist

CONNECTED **AND** AUTONOMOUS VEHICLES (CAVS)

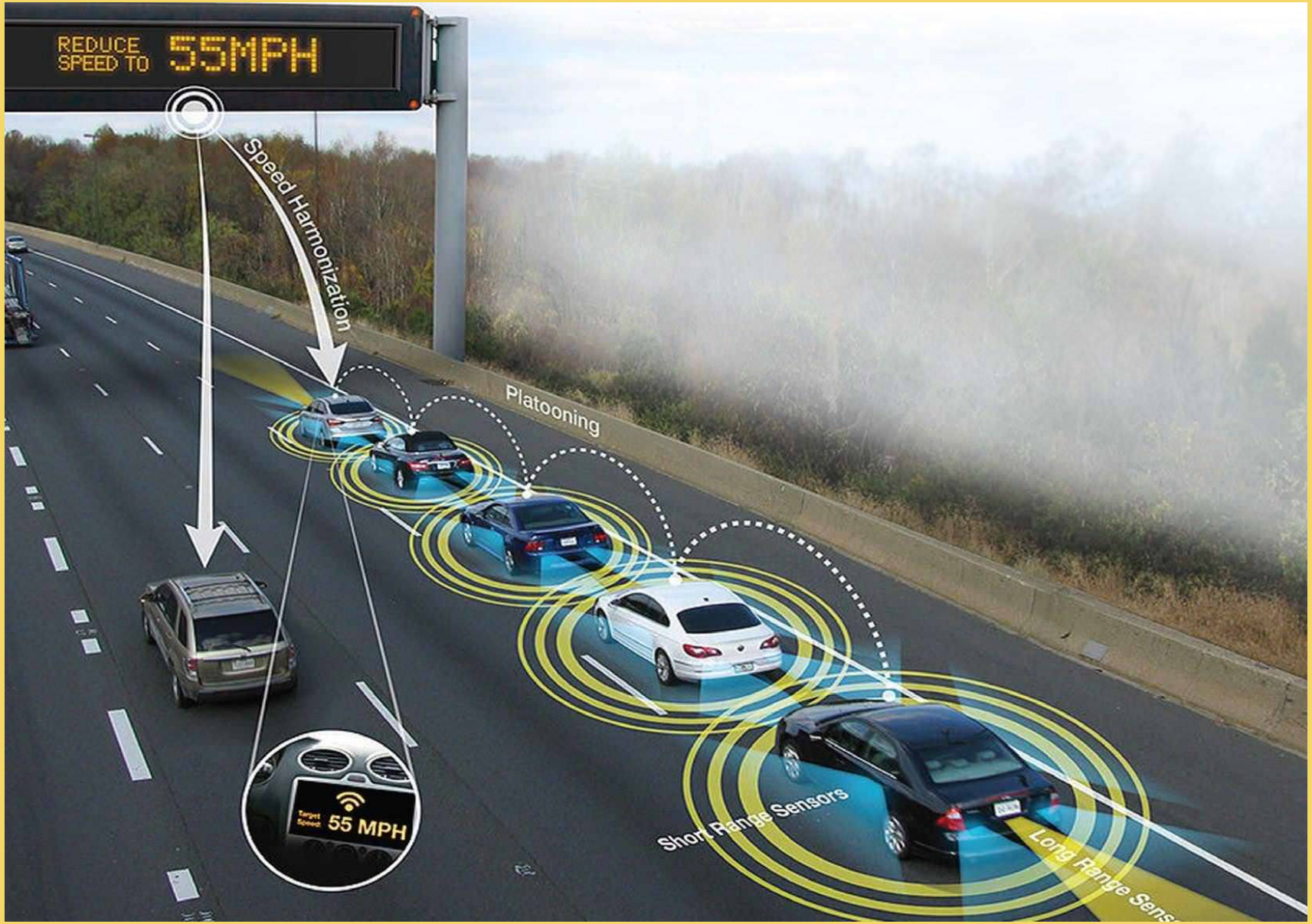
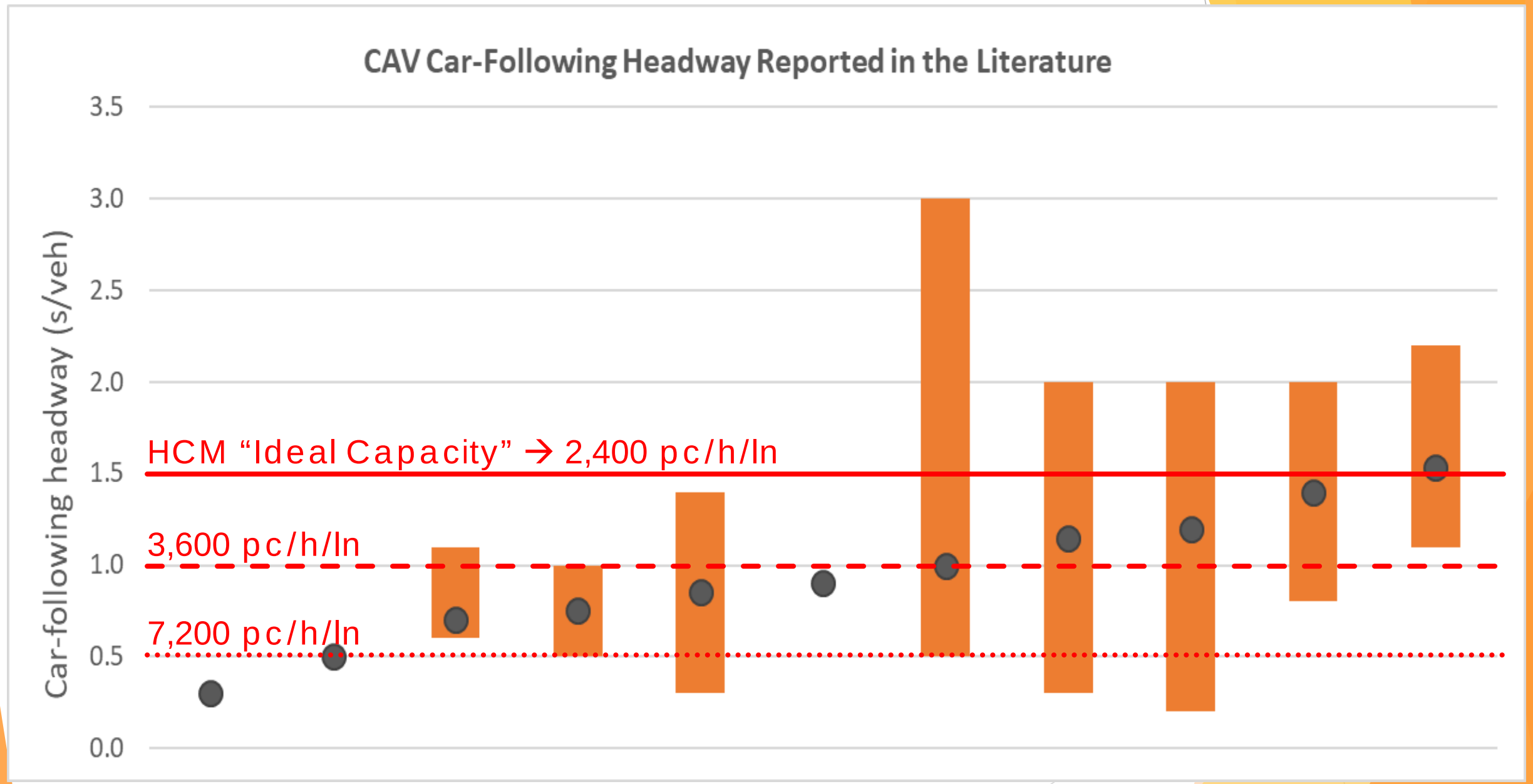


Image Credit: PCQuest



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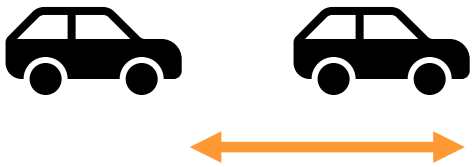
… THE PROBLEM WITH MOST CAV STUDIES

… at 70 mi/h travel speed

2,400 pc/h/ln
→ 1.5 seconds → 154 feet

3,600 pc/h/ln
→ 1.0 seconds → 103 feet



7,200 pc/h/ln
→ 0.5 seconds → 51 feet

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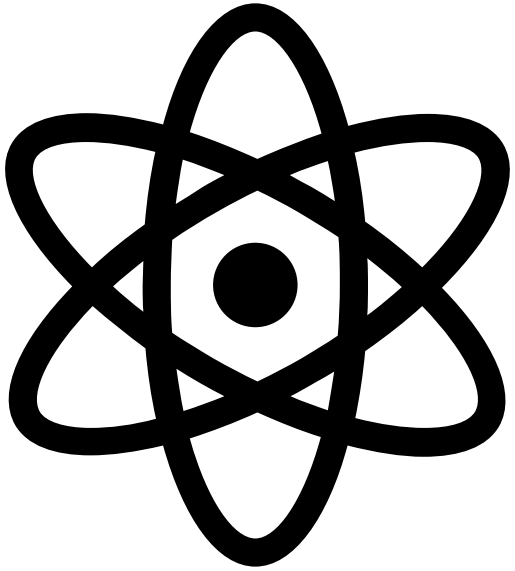
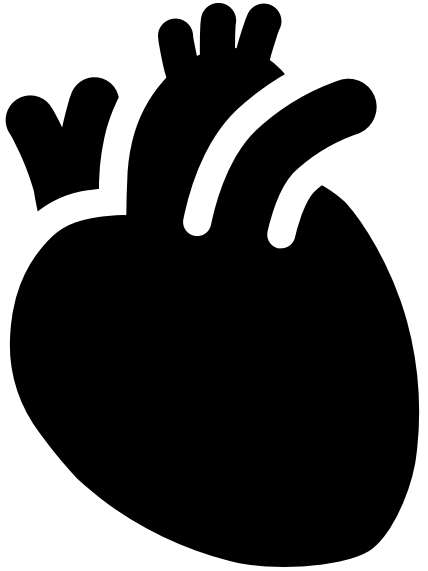


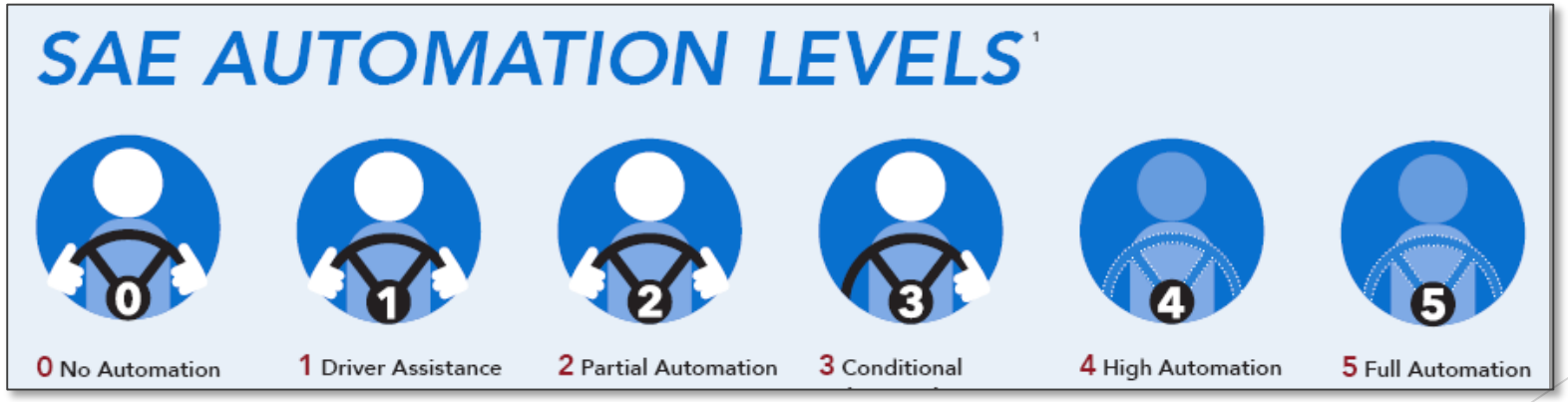


What is Capacity?

- The inverse of following headway
- Function of:
  - Perception-Reaction Time
  - Physics
  - Level of Stress
- Lower at bottlenecks than basic segments

CAV ADOPTION TIMELINE

- **U.S. Light Duty Fleet Turnover Rate: 14.8 years**
- **Technology availability:**
  - Partial Automation (Levels 1-2): 2017-2019
  - Conditional Automation (Level 3): 2020 (limited operational design domains)
  - High/Full Automation (Levels 4-5): 2025-2030
- **Market Penetration:**
  - Once technology is perfected, it will take another 13 years for 50% market penetration and 27 years for 90% market penetration



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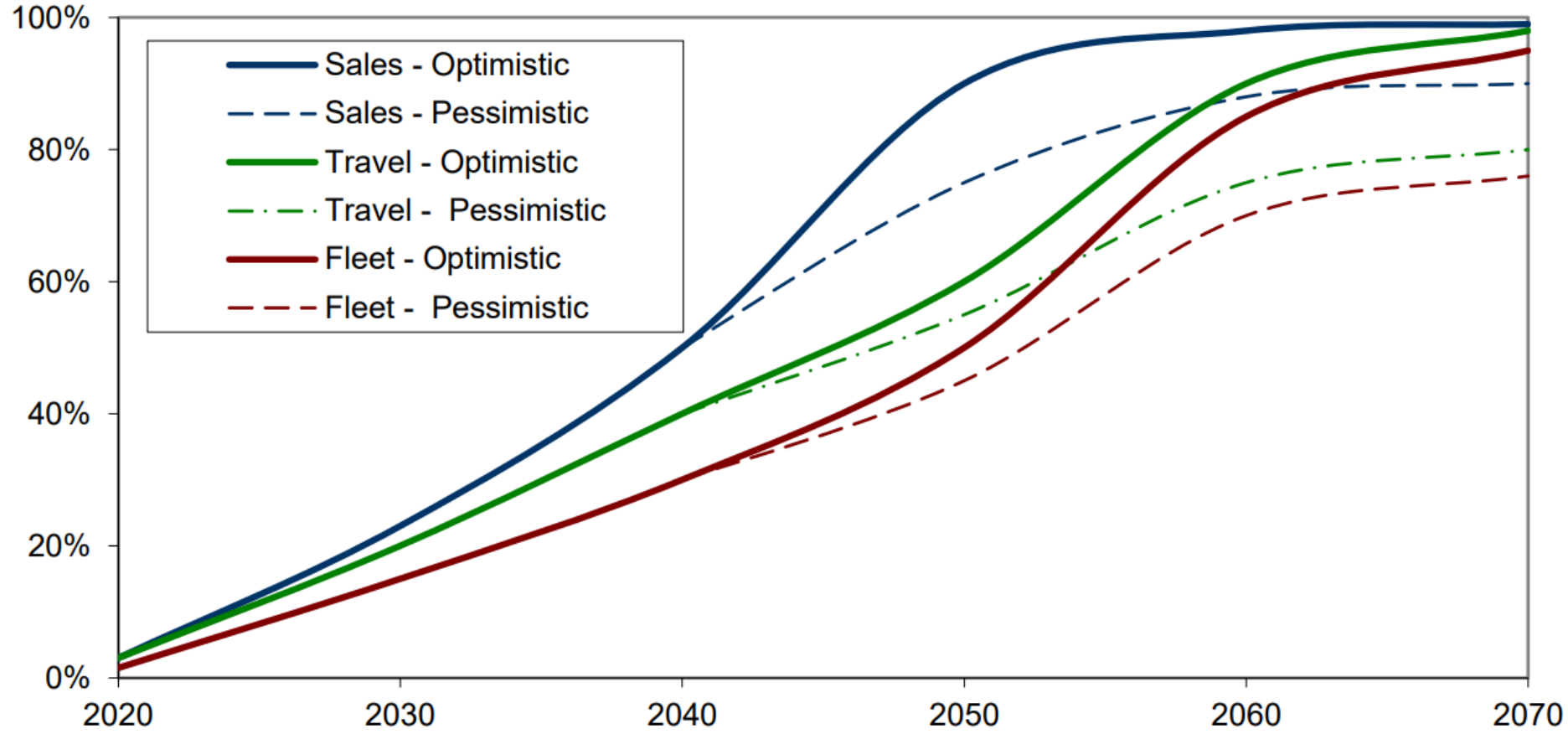
CAV ADOPTION TIMELINE

Exhibit 14 **Autonomous Vehicle Sales, Fleet and Travel Projections** (Based on Exhibit 13)

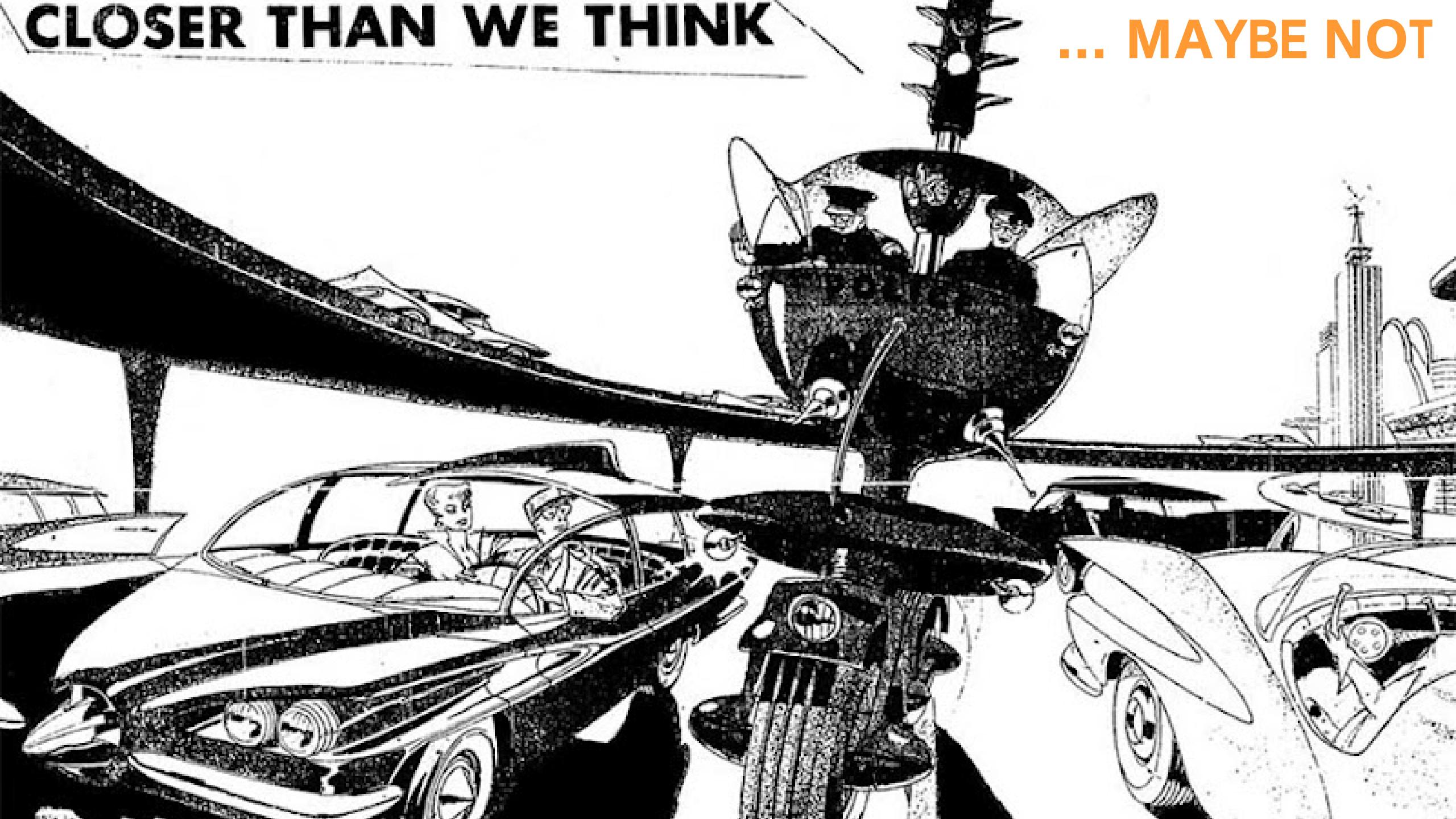


If they follow previous vehicle technologies autonomous vehicles it will take one to three decades to dominate vehicle sales, and one or two more decades to dominate vehicle travel, and even at saturation a significant portion of vehicle travel may continue to be human operated, indicated by the dashed lines.

Source: Litman, Todd, 2018. Autonomous Vehicle Implementation Predictions. https://www.vtpi.org/avip.pdf

CLOSER THAN WE THINK

... MAYBE NOT



ASSUMPTIONS

- Headways and Oscillation
- Platooning
- Cooperation
- Market Penetration
- Number of Lanes
- Volume Mix

Modeling Framework (Freeways)

Basic Freeway Segments

- 2-Lane vs. 3-Lane Segment
- ACC Only vs. CACC (platooning)
- Market Penetration Rate
- Parameter Sensitivity

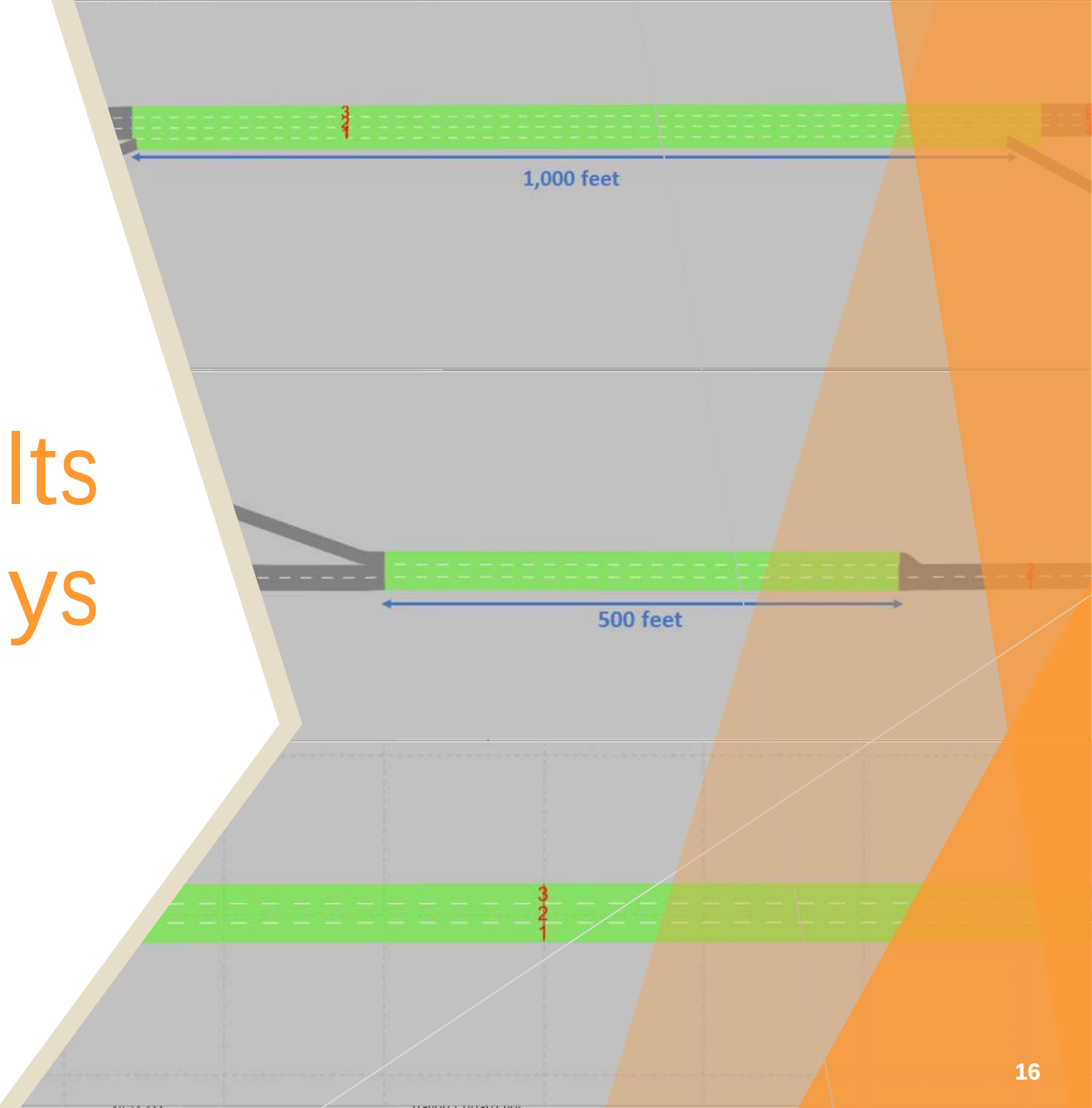
Freeway Merge Segments

- With and without Advanced Merge
- Market Penetration Rate
- Volume Balance

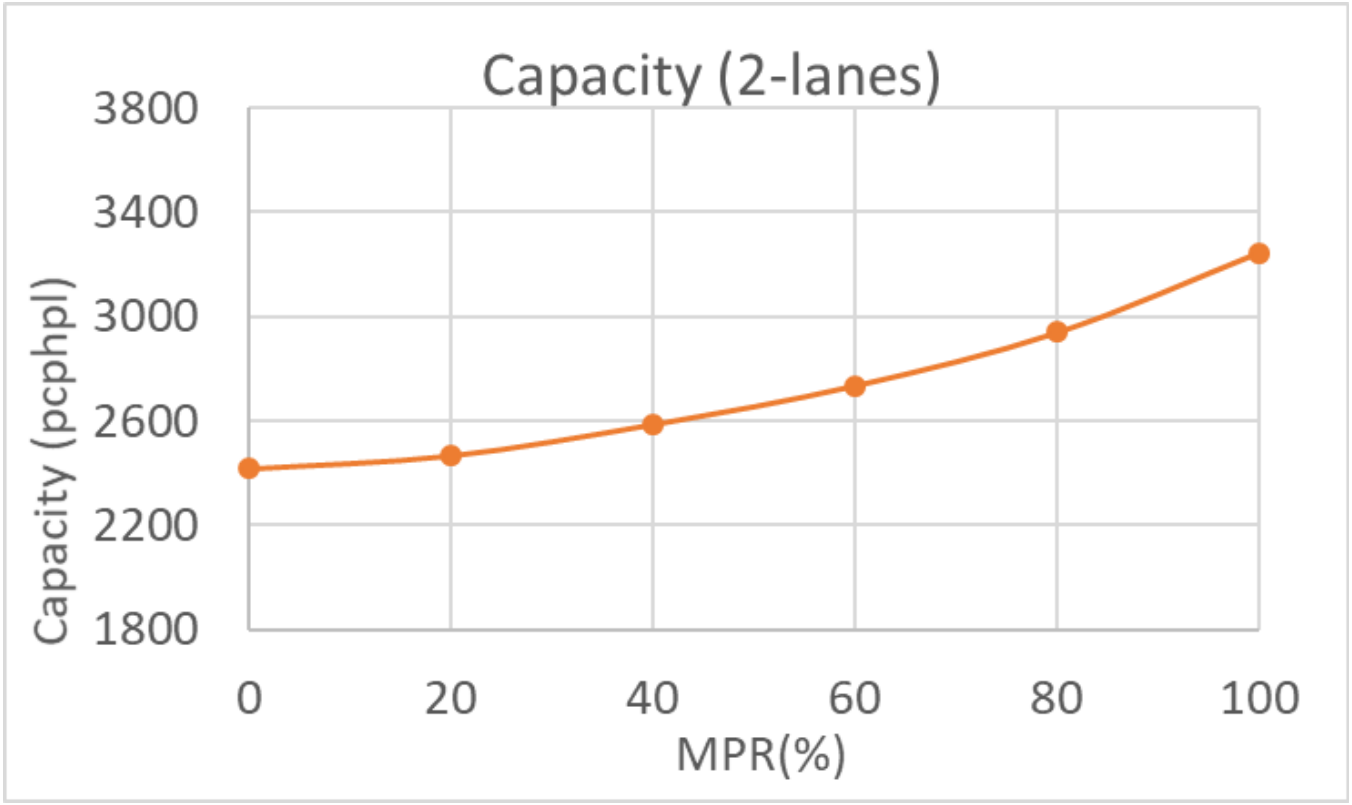
Freeway Weaving Segments

- With and without Advanced Merge
- Market Penetration Rate
- Weaving Intensity

Draft Results
Freeways

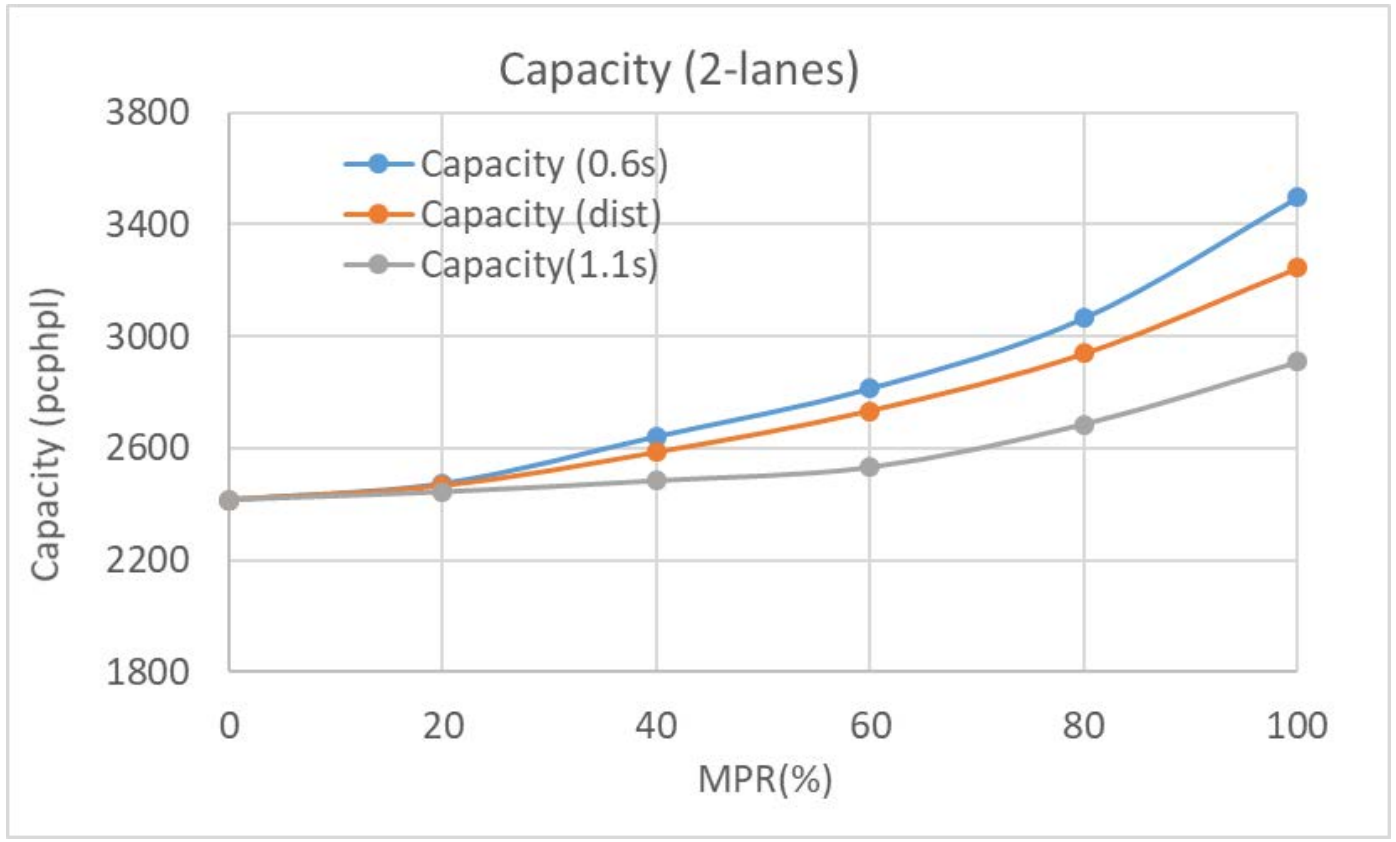


Basic Freeway Segments → Effects of Market Penetration



Steady Increase in Capacity with Increasing Market Penetration

Basic Freeway Segments → Platooning Effects (Intra-platoon Gap)



Capacity function of "Intra-Platoon Gap" Setting

→ Average Distribution Used for Results

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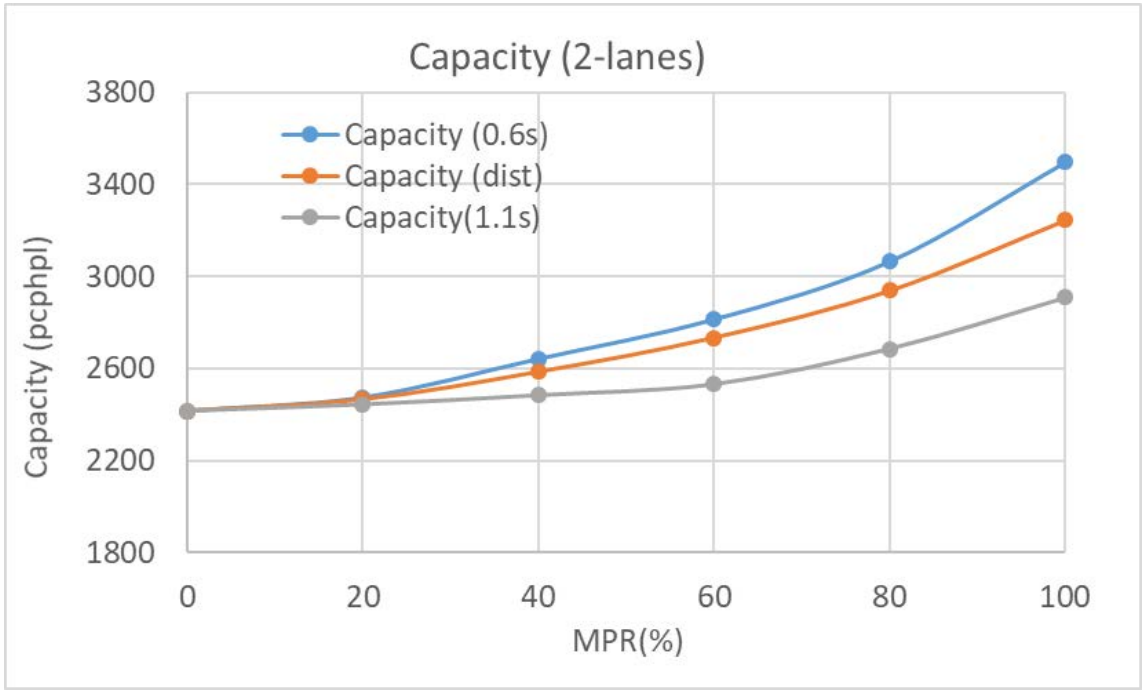
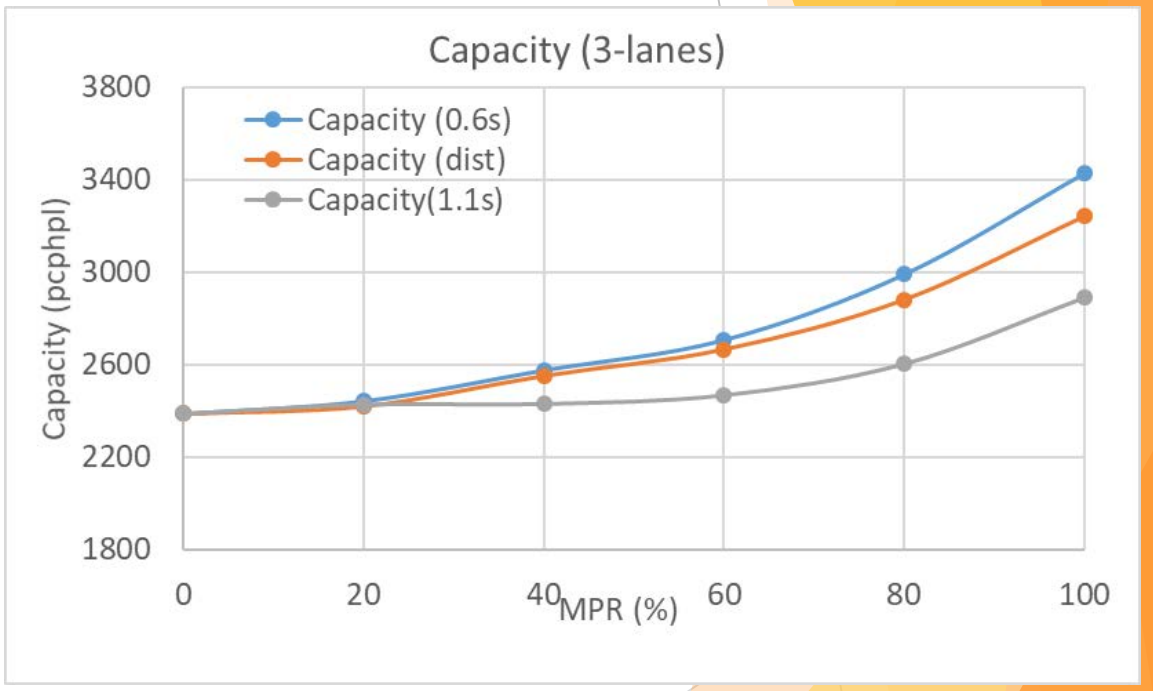
Basic Freeway Segments → 2-Lane vs. 3-Lane





Capacity follows same trends for 2-lane and 3-lane Segments

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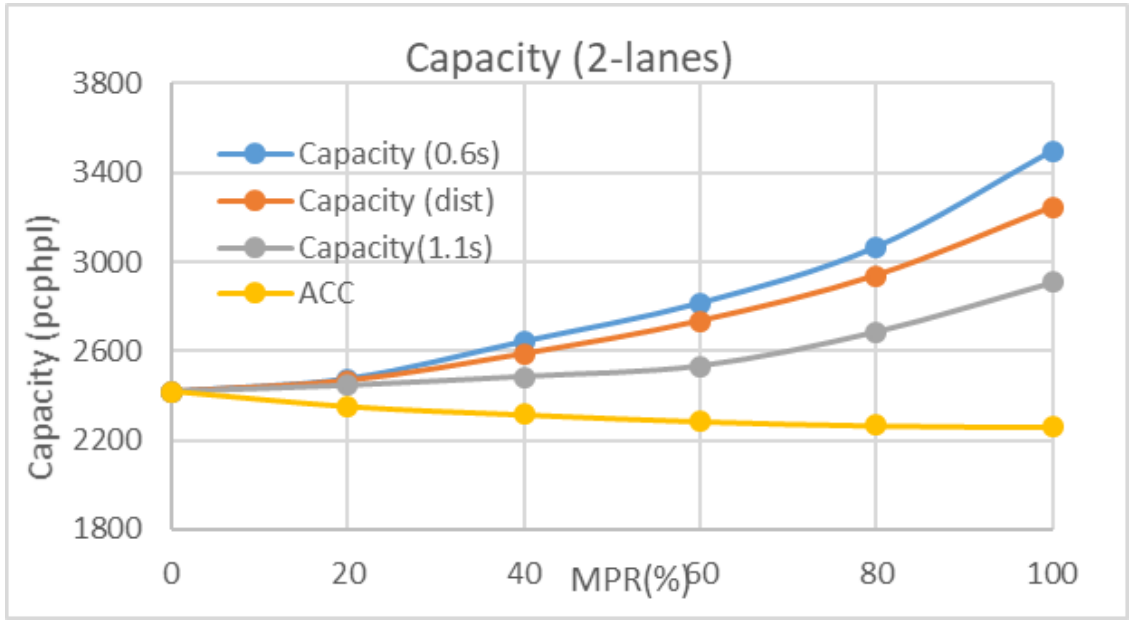
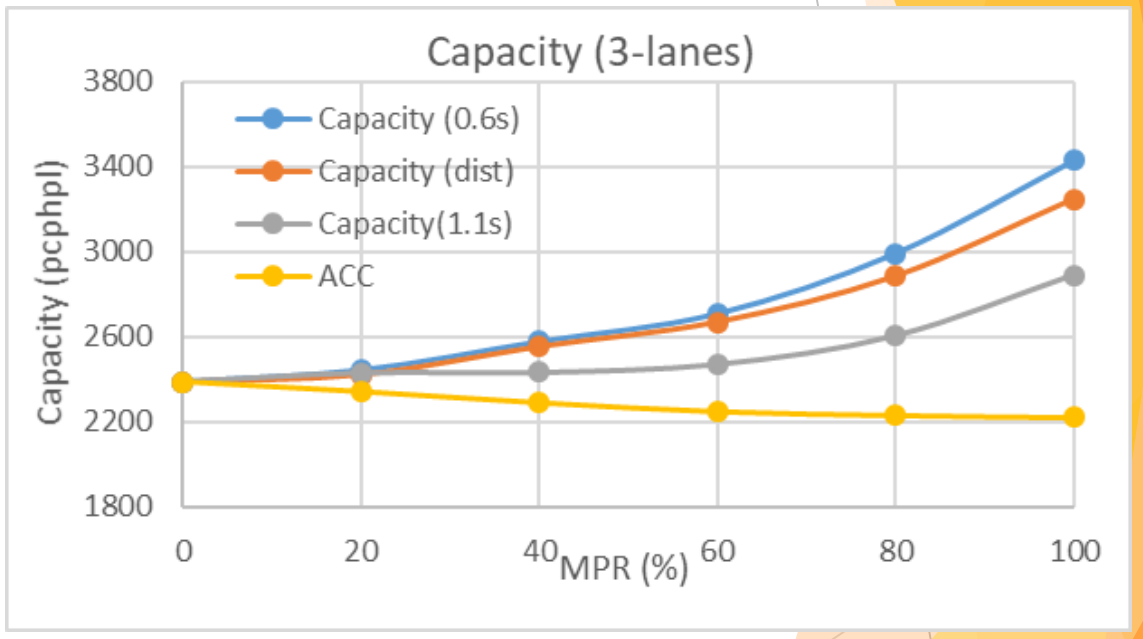
Basic Freeway Segments → ACC vs. CACC





Capacity significantly lower with ACC (Autonomous Vehicles without Platooning)

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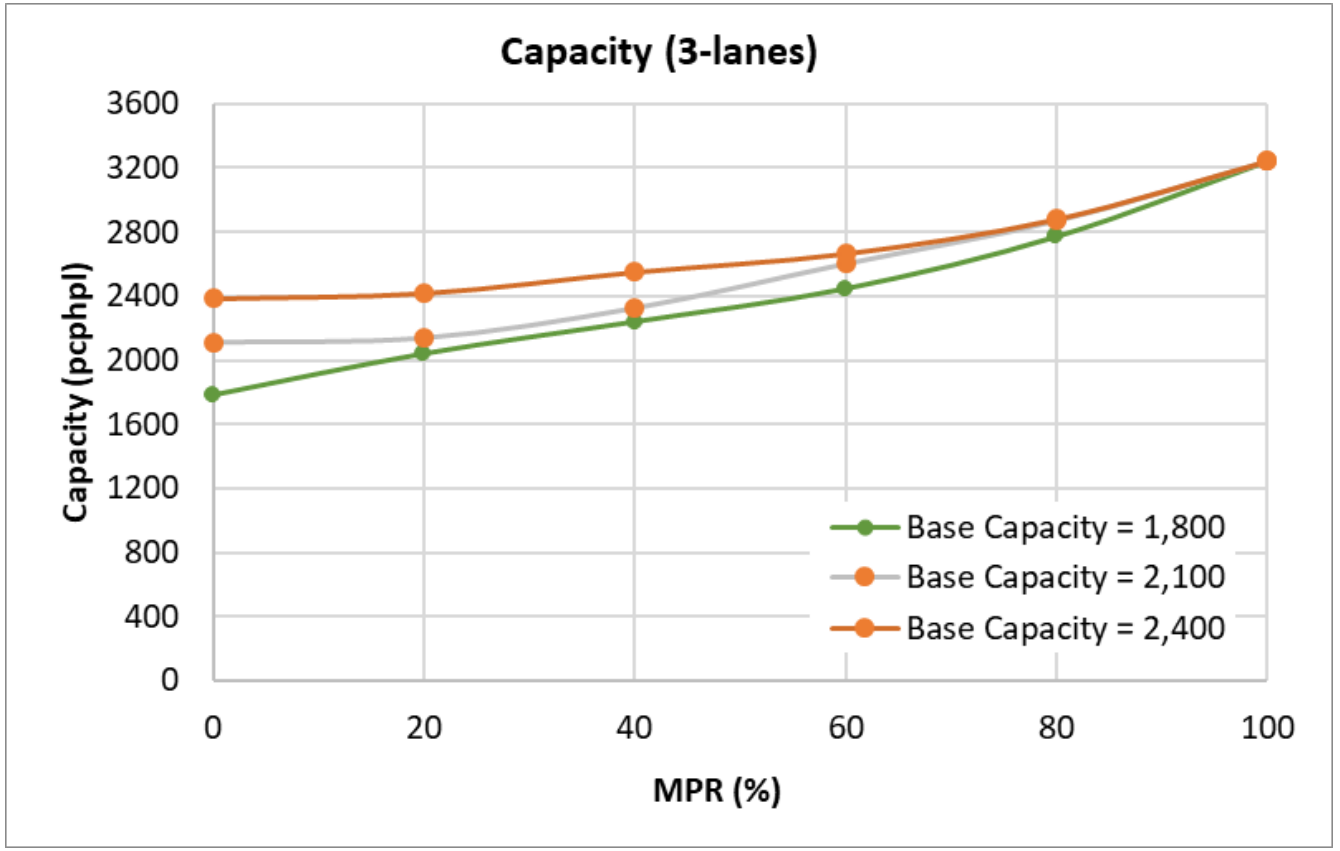
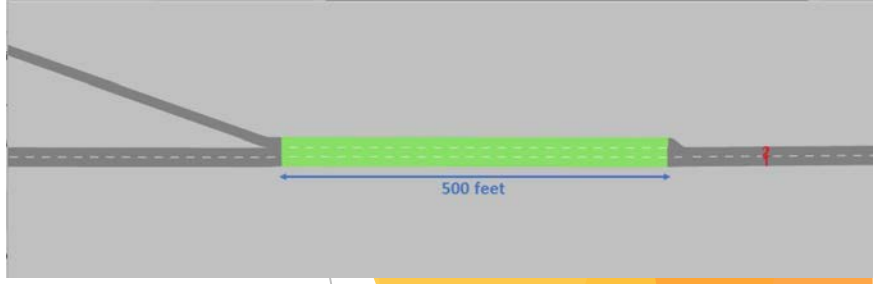
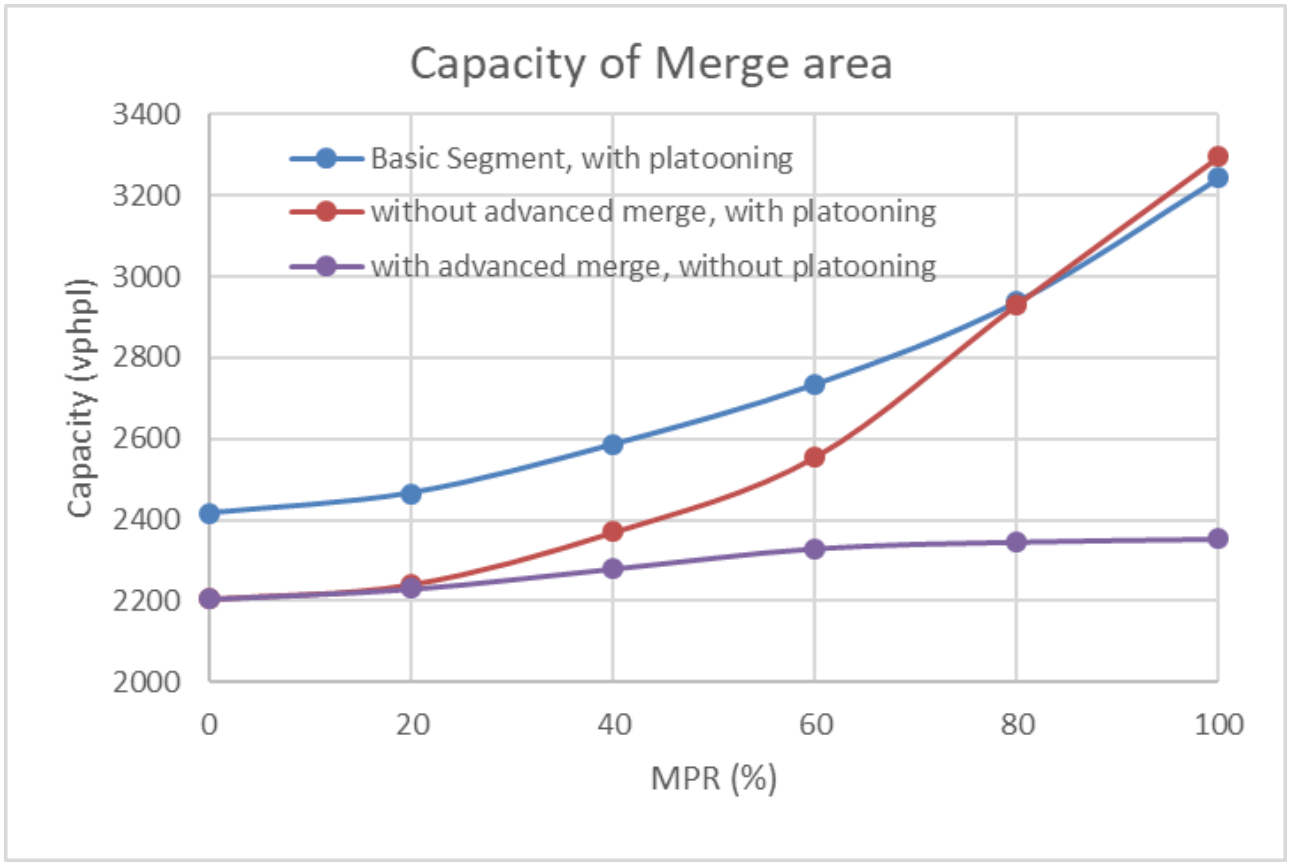
Basic Freeway Segments → Varying Base Capacity



Capacity converges at same point, despite varying calibrated base capacities (e.g. bottleneck capacities)

Freeway Merge Segments → Effects of Platooning





Platooning is essential to achieve merge area capacity benefits with CAVs

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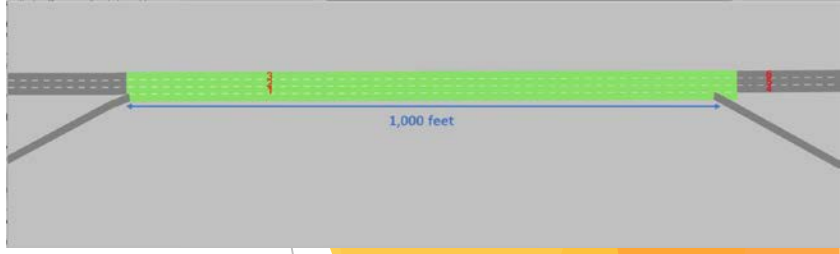
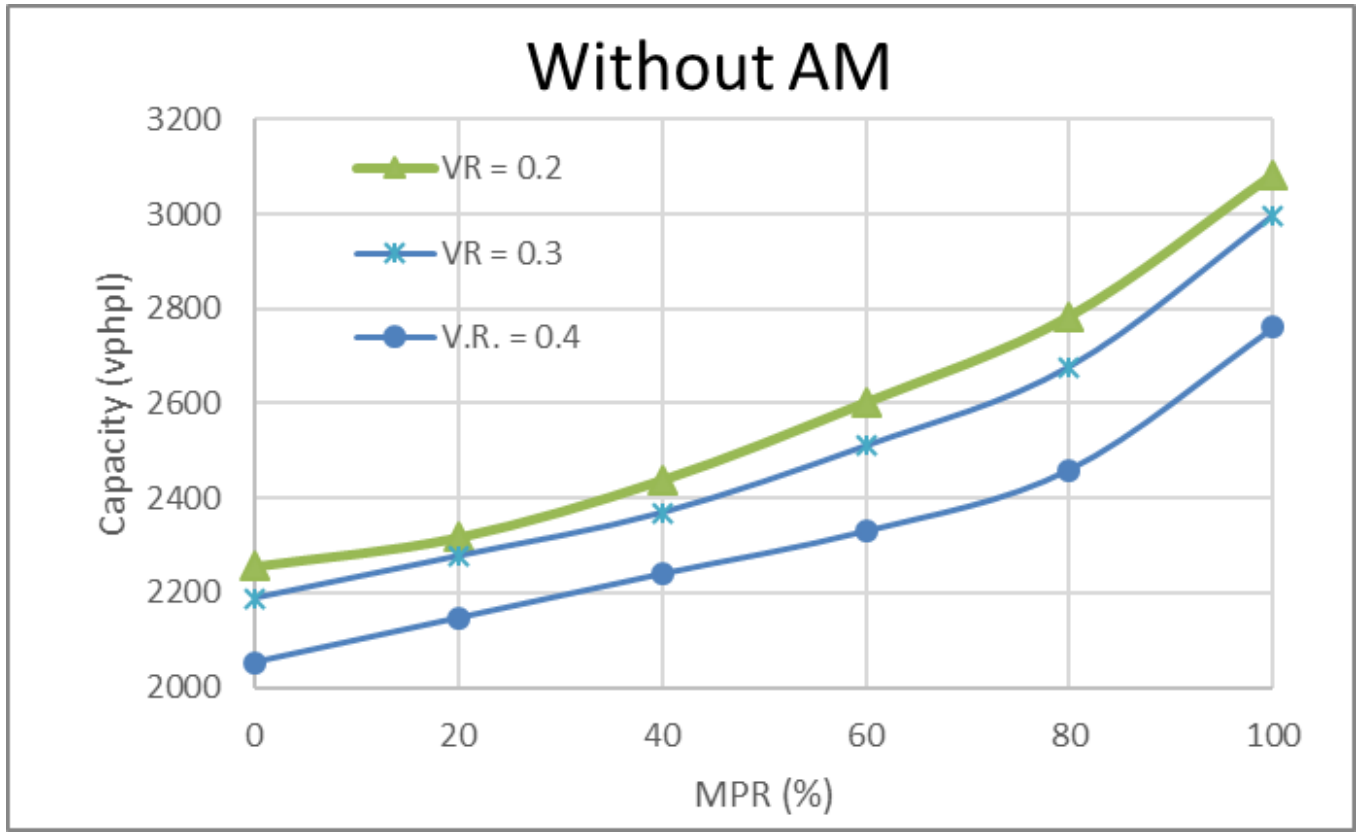


Freeway Weaving Segments
→ Effects of Volume Ratios without Advanced Merge



Capacity decreases with higher volume ratio

MPR effects consistent across VRs (similar slopes)

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HCM

- Implementation

Draft CAF Tables – Basic Segments

2-lane	Base Capacity (pc/h/ln)		
MPR (%)	2,400	2,100	1,800
0	1.00	1.00	1.00
20	1.02	1.03	1.14
40	1.07	1.10	1.27
60	1.13	1.26	1.43
80	1.22	1.37	1.63
100	1.34	1.52	1.82

3-lane	Base Capacity (pc/h/ln)		
MPR (%)	2,400	2,100	1,800
0	1.00	1.00	1.00
20	1.01	1.01	1.15
40	1.07	1.10	1.26
60	1.12	1.23	1.37
80	1.21	1.36	1.56
100	1.36	1.54	1.82

Draft CAF Tables – Merge Segments

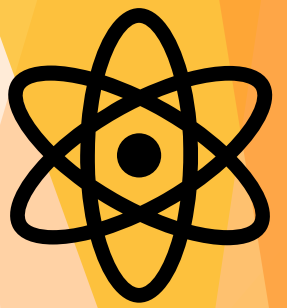
	%MPR					
	0	20	40	60	80	100
No onramp	1.00	1.02	1.07	1.13	1.22	1.34
without AM, with PLAT	1.00	1.02	1.07	1.16	1.33	1.49
with AM, with PLAT	1.00	1.07	1.11	1.21	1.35	1.50
with AM, without PLAT	1.00	1.01	1.03	1.06	1.06	1.07

Draft CAF Tables – Weaving Segments

without AM	% MPR					
VR	0	20	40	60	80	100
0.2	1.00	1.03	1.08	1.15	1.23	1.37
0.3	1.00	1.04	1.08	1.15	1.22	1.37
0.4	1.00	1.05	1.09	1.13	1.20	1.34
with AM	% MPR					
0.2	1.00	1.05	1.11	1.17	1.25	1.37
0.3	1.00	1.05	1.13	1.20	1.26	1.38
0.4	1.00	1.08	1.14	1.18	1.24	1.35

Closing Thoughts

- CAVs will likely increase capacities, but
  - … not as soon as you may think
  - … not as much as media may suggest
- Actual capacity is a function of many factors and assumptions
- Planning-level estimates can help inform decision-making, but agencies should understand modeling assumptions
- Dedicated CAV-Only Facilities may happen sooner



QUESTIONS AND DISCUSSION