Effect of Heterogeneity due to Levels of Automation on Operational Performance of Freeways: A Microsimulation Based Approach

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Introduction

- # of vehicles on the roads has been growing over the past few years
- Autonomous vehicles (AVs) are expected to enhance the operational performance of the existing transportation system
- Level 1 AVs (with adaptive cruise control or lane keep assist) and level 2 AVs (with adaptive cruise control and lane keep assist working in tandem) have already started to penetrate into the market
- Penetration of AVs with different levels of automation would increase the heterogeneity in traffic

Introduction

	Equipped smart features	What those features can do
SAE Level 0	Automated emergency braking Blind spot warning Lane departure warning	Warning and momentary assistance
SAE Level 1	Lane centering **or** Adaptive cruise control	Steering **or** braking/accelerating support
SAE Level 2	Lane centering **and** Adaptive cruise control	Steering **and** braking/accelerating support
SAE Level 3	Autopilot system Traffic jam chauffeur	Can drive the vehicle under **limited conditions**

Source: SAE Levels of Driving Automation™ Refined for Clarity and International Audience. https://www.sae.org/blog/sae-j3016-update

Need for the Research

Mimicking the exact driving behavior and predicting the scenario after the introduction of AVs

- Help identify the potential challenges at higher penetration rates

Identifying the potential effect of penetration of various levels of AVs on operations

- Better planning for infrastructure modifications

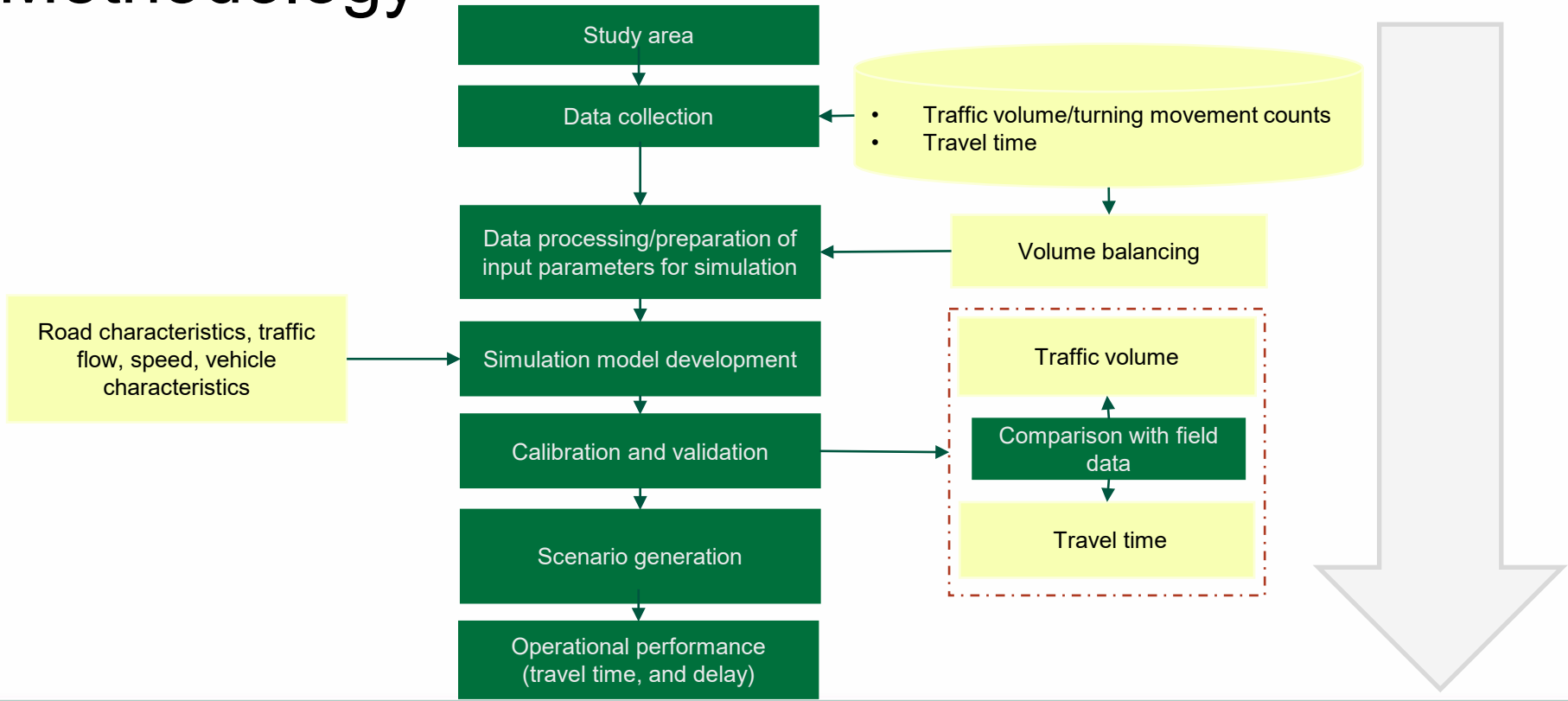
Why freeways?

- Freeways account for ~2.6% of all road lane miles in the United States and carry ~26% of the nation's vehicle travel

Research Objectives

- Identify the driving behavior parameters to mimic vehicles with different levels of automation
- Review and identify the forecasted penetration rates of various levels of AVs
- Develop and calibrate microsimulation model to mimic the existing driving conditions
- Identify the effect of different levels of AVs and heterogeneity due to the mix of AVs on freeways

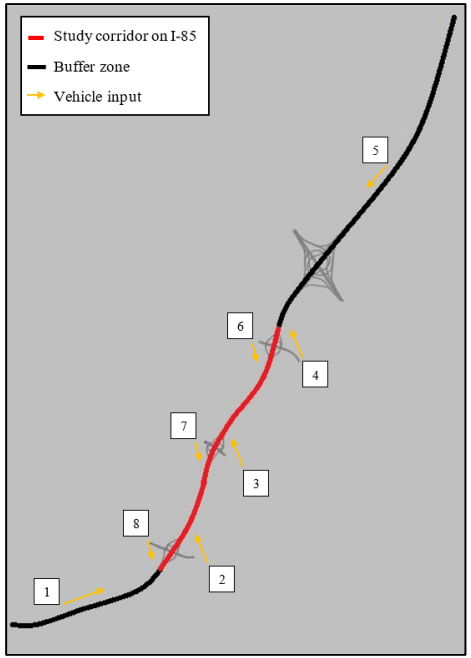
Methodology



Study Area



Study Corridor Location
(Satellite Images © 2022 Google)



Study Corridor in PTV Vissim Interface

- 3.2-mile section on I-85 [Begins at exit 43 (NB) and ends at exit 47 (SB)]
- 2-mile buffer on each side
- Vehicle input provided from 8 different locations
- Five lanes in each direction
- Speed limit: 65 mph
- Functional class: Freeway

Data Collection and Processing

- Vehicular volumes, signal timings, and road inventory data
- Turning movement counts and signal information for intersections (obtained from the city of Charlotte)
- Travel time and speed data for study corridors from private data sources
- Comparison of computed vehicular volumes with the Metrolina Planning model output
- Volume estimation for freeways using AADT, peak hour factor & directional split
- Volume balancing to remove imbalances between multiple intersections along the corridors

Development of Simulation Model

- Road geometry, vehicle volume inputs, conflict areas, speed distributions, and speed decision inputs are provided
- Model calibration was performed using driver behavior parameters (car following and lane change characteristics)
  - Adjusted based on the past literature synthesis and PTV Vissim CoExist Project
- Model validation: Comparison with probe travel times and vehicle volumes

Driving Behavior Parameters

Wiedemann 99 and lateral model parameter	Level 0	Level 1	Level 2	Level 3
Standstill distance - CC0 (feet)	4.92	4.92	4.92	3.28
Headway time- CC1 (seconds)	0.90	0.60	0.60	0.60
Following variation - CC2 (feet)	13.12	6.56	6.56	0.00
Threshold for entering following - CC3 (seconds)	-8.00	-8.00	-8.00	-6.00
Negative speed difference during following process - CC4 (feet per second)	-0.35	-0.33	-0.33	-0.33
Positive speed difference during the following process - CC5 (feet per second)	0.35	0.33	0.33	0.33
Speed dependency of oscillation - CC6 (feet per second)	11.44	0.00	0.00	0.00
Oscillation acceleration - CC7 (feet per second square)	0.82	0.82	0.82	0.33
Standstill acceleration - CC8 (feet per second square)	11.48	11.48	11.48	13.12
Desired acceleration at 50 mph - CC9 (feet per second square)	4.92	4.92	4.92	6.56
Desired position at free flow	Any	Any	Middle of the lane	Middle of the lane

Scenarios

1. Forecasted penetration rate for each year with base year traffic volume
   - To identify the effect of the forecasted penetration rate on delay per vehicle
2. Hypothetical conditions with all vehicles of the same level of automation varying from level 0 to level 3
   - To test the effect of AVs under homogeneous traffic conditions
3. All conditions tested in scenarios 1 and 2 with forecasted traffic volume
   - To identify the futuristic conditions incorporating a mix of AVs and increase in traffic

Simulation Setup

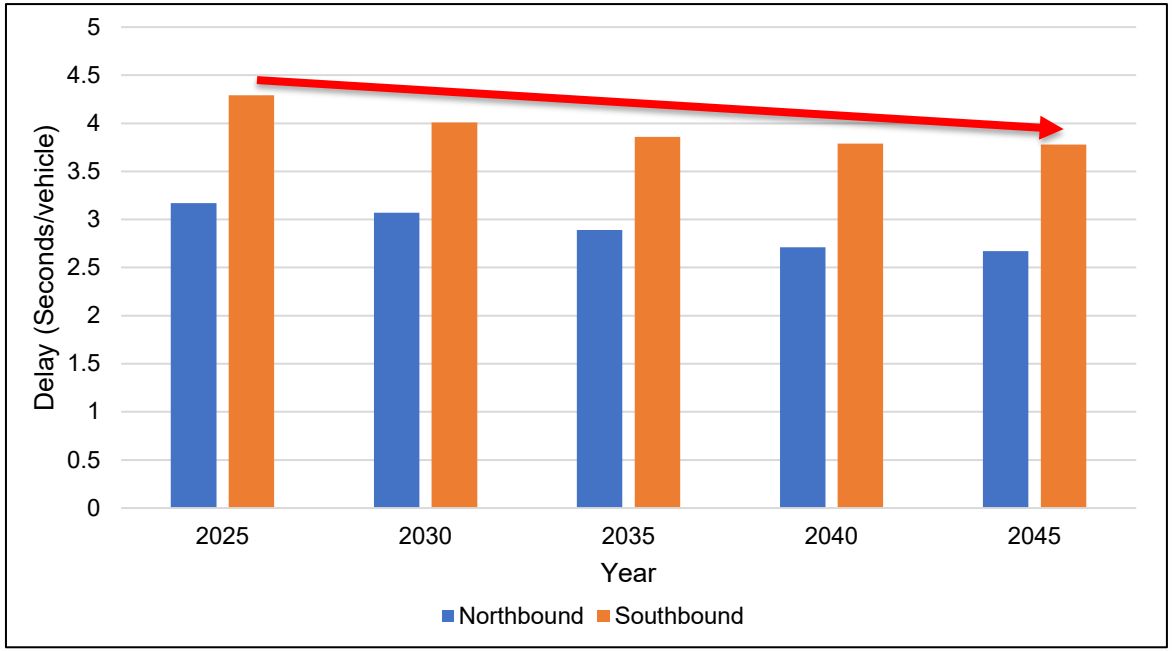
- Three simulation runs were conducted with varying random seed numbers, for each scenario and condition
- 102 simulation runs were carried out in total for three scenarios
  - Scenario 1: 15 simulation runs (3 * 5 years)
  - Scenario 2: 12 simulation runs (3 * 4 levels of automation)
  - Scenario 3: 75 simulation runs (3 * 5 years * 5 traffic conditions)
- Network level travel time and delay were considered as measures of operational performance

Simulation of AVs using PTV Vissim



Results

Effect of Penetration of Different Levels of AVs on Delay



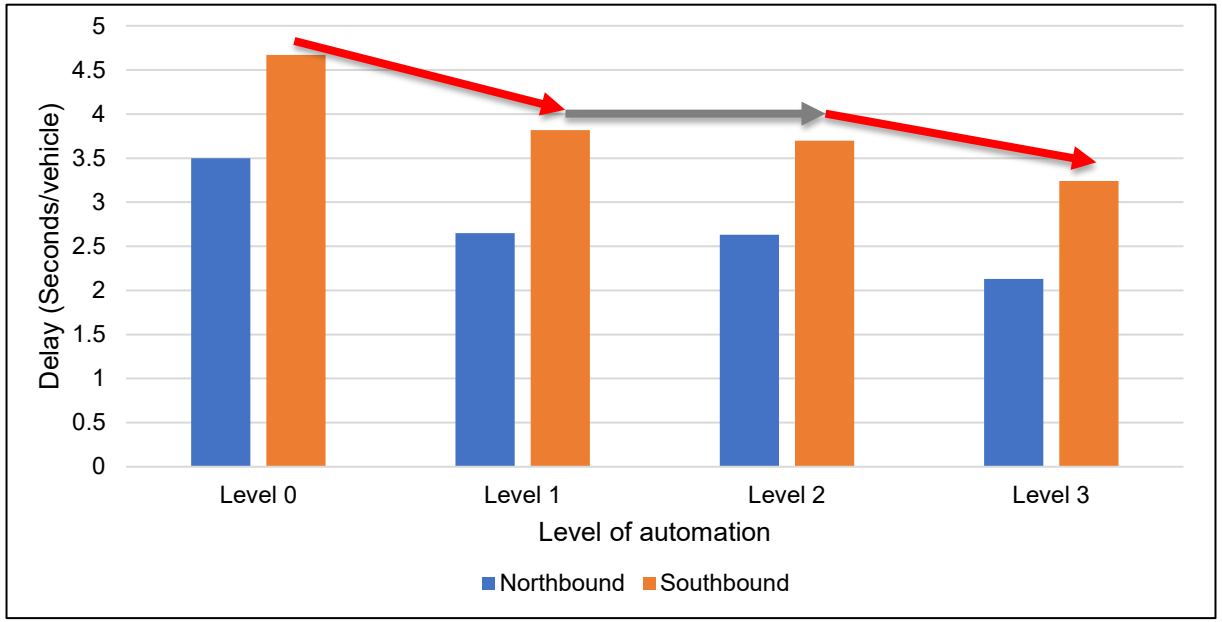
Used penetration rates corresponding to the year (%)

SAE Level	2025	2030	2035	2040	2045
Level 0	71.1	57.4	43.9	32.6	23.6
Level 1	6.7	6.6	6.9	5.2	4.6
Level 2	5.0	6.9	7.7	7.4	7.3
Level 3	17.2	29.1	41.5	54.8	64.5

Source: Bansal and Kockelmann, 2017. Forecasting Americans' Long-Term Adoption of Connected and Autonomous Vehicle Technologies. Transportation Research Part A: Policy and Practice, 2017. 95:49-63.

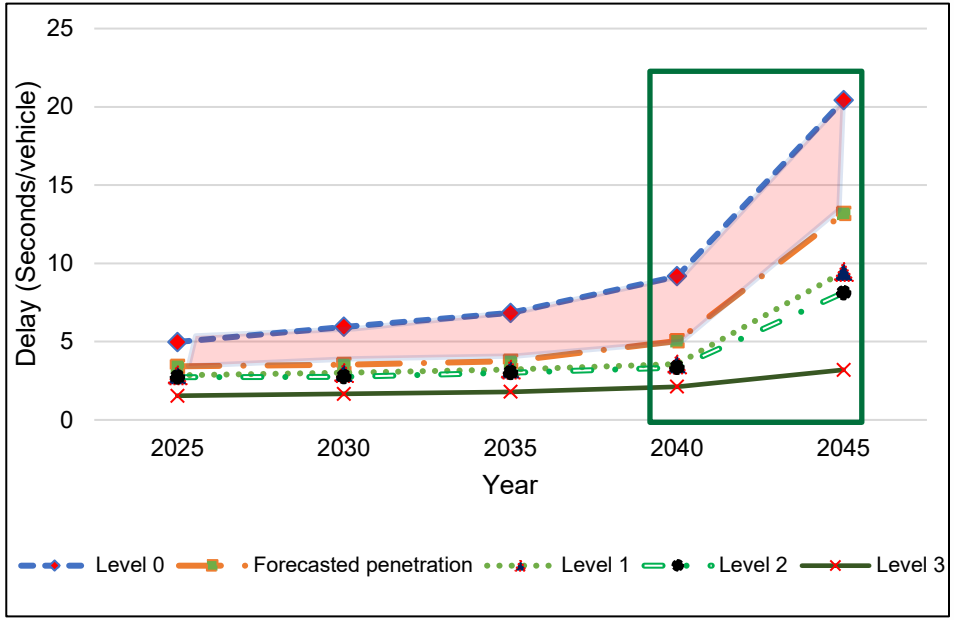
Results (Cont.)

Effect of Levels of Automation on Delay

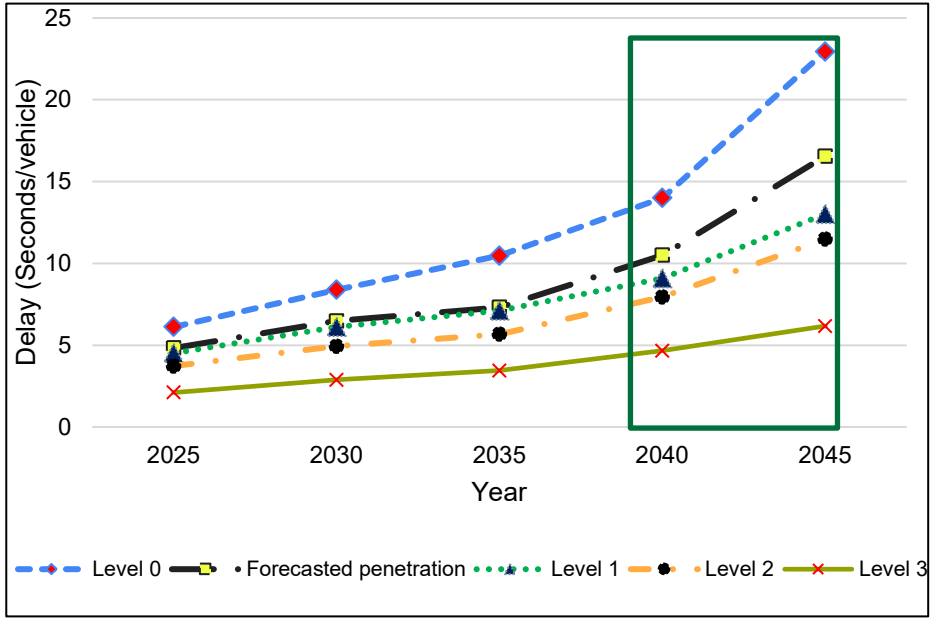


Results (Cont.)

Corridor Level Delay Variation



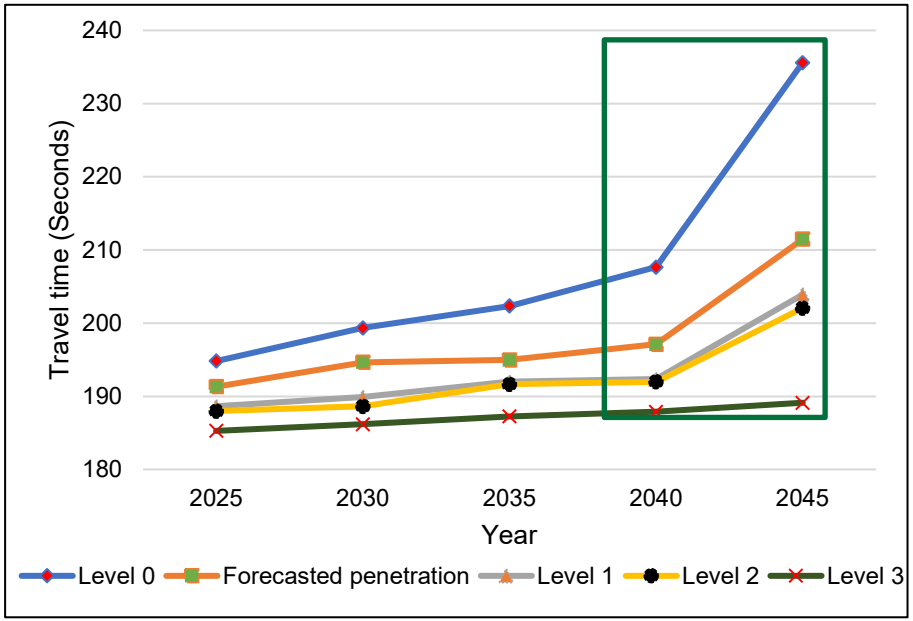
Northbound



Southbound

Results (Cont.)

Corridor Level Travel Time Variation



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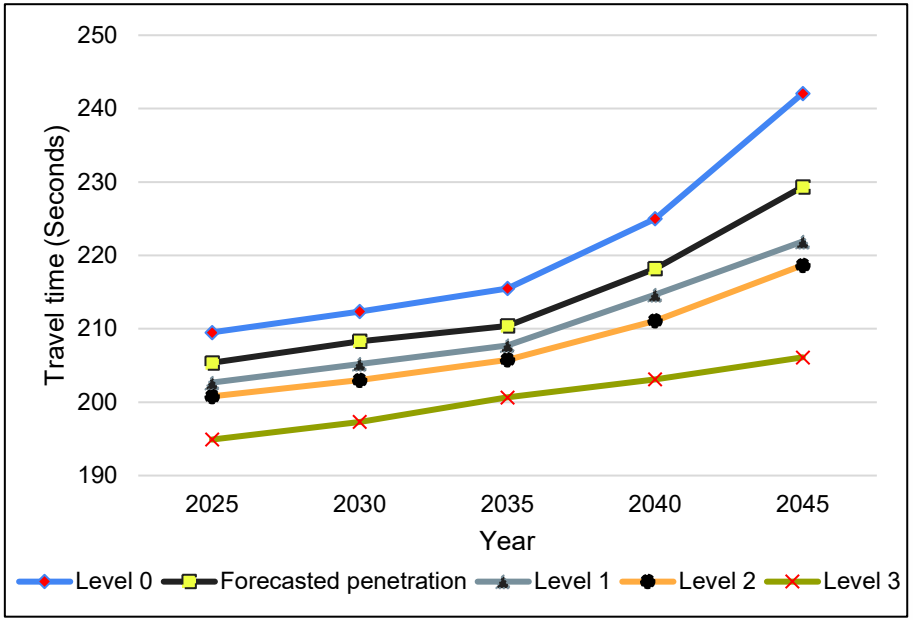

Southbound

Conclusions

- Effect of lane centering feature on operational performance is negligible (2.1% and 0.7% for NB and SB direction considering delay)
- Adaptive cruise control feature has a positive effect on the operational performance of freeways (24.2% and 18.2% for NB and SB direction)
- Operational performance of a mix of different levels of AVs is better compared to the scenario with all non-automated vehicles
- Operational performance of study area improves significantly at more than 29% penetration of level 3 AVs
- Heterogeneous conditions due to a mix of different levels of AVs reduces operational performance

Conclusions (Cont.)

- Without any modification to existing infrastructure, the study area can cater to traffic demand till 2040, considering forecasted penetration of AVs and projected increase in traffic demand
- Delay per vehicle for level 3 AVs is 19% less compared to level 1 and level 2 AVs, showing higher operational benefits of automated driving system

Limitations and Scope for Future Work

- Forecasted penetration rates were considered in the analysis
  - Results may vary depending on the penetration of various levels of AVs
- Effect of AVs on the capacity of freeways is not explored in this study
- The connected and autonomous vehicles with vehicle-to-vehicle and vehicle-to-infrastructure communication are not considered in the given study
- The results may vary depending on the road geometry and area
  - Determining the effect of AVs on rural freeway corridors is identified as future scope

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