Tran-SET

Transportation Consortium of South-Central States

# Traffic Flow Impacts of Adaptive Cruise Control and Cooperative Adaptive Cruise Control: An Investigation using Microscopic and Mesoscopic Models

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# Presentation Topics



- O — Obligations
- S1 — Characterizing the Impact of Production Adaptive Cruise Control on Traffic Flow: An Investigation
- S2 — Dynamic Traffic Assignment of Cooperative Adaptive Cruise Control

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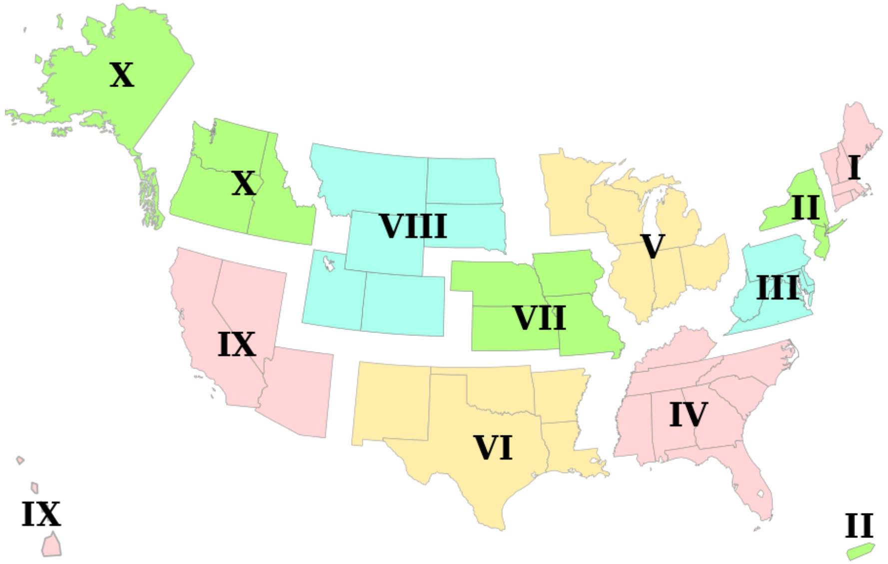
DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

# Introduction

# Tran-SET

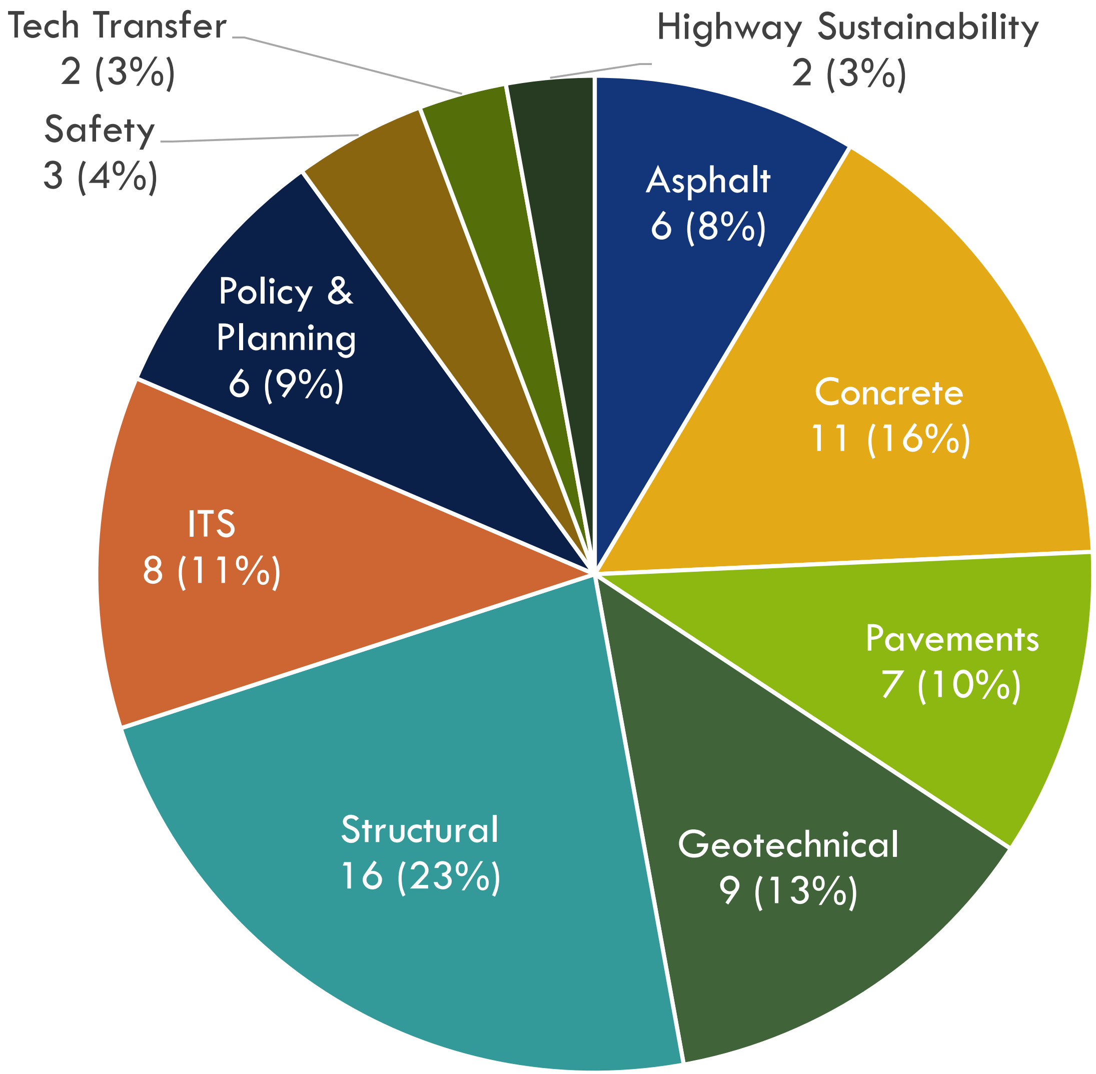


- USDOT – University Transportation Centers (UTC) Program
  - National (5), Regional (10), and Tier 1 (20)
- Tran-SET
  - Grantee of Region 6 UTC
  - Consortium of 11 partnering institutions



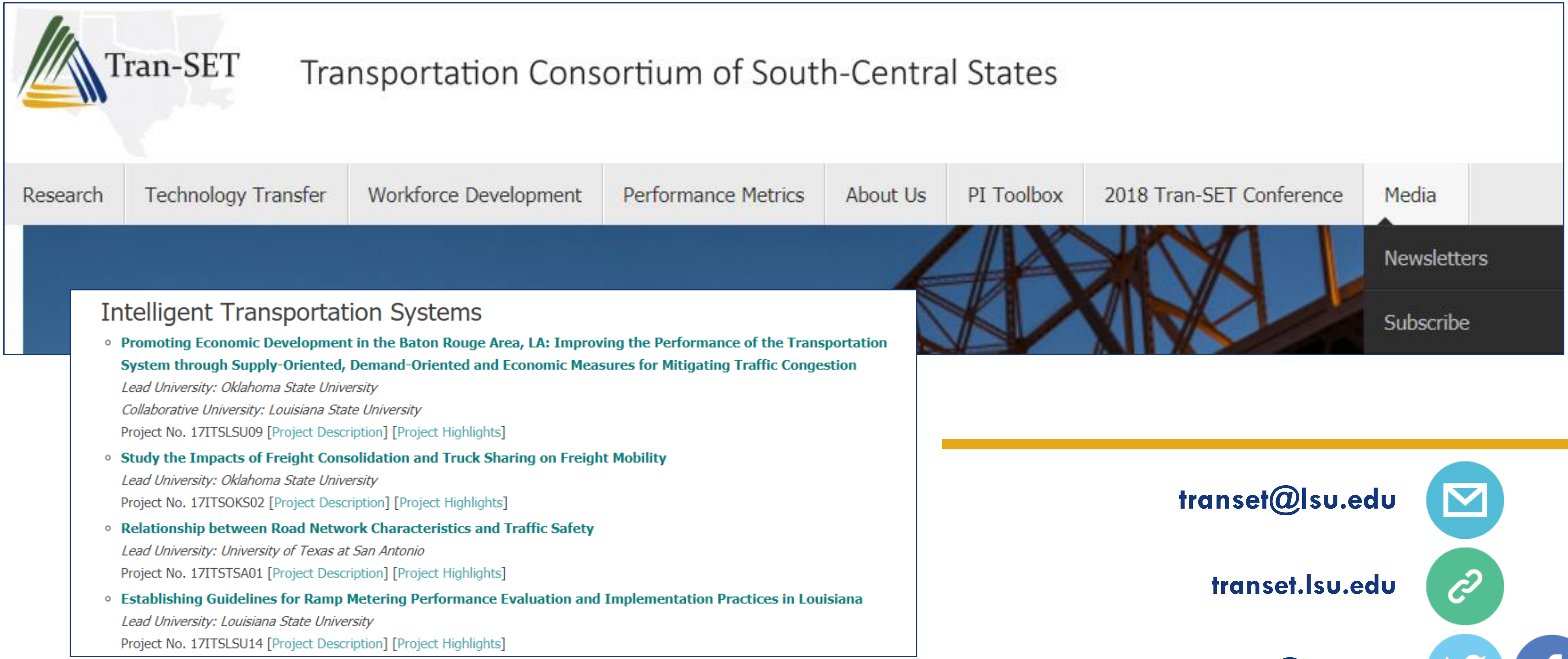
# Tran-SET Research

- Research Themes
  - Enhancing durability and service life of infrastructure
  - Preserving existing transportation systems
  - Preserving the environment
  - Addressing immediate Region 6 transportation needs
- 70 research projects (33 FY17, 33 FY18)
- $9.1million in research funds



# Tran-SET Website



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# FHWA-Related Efforts

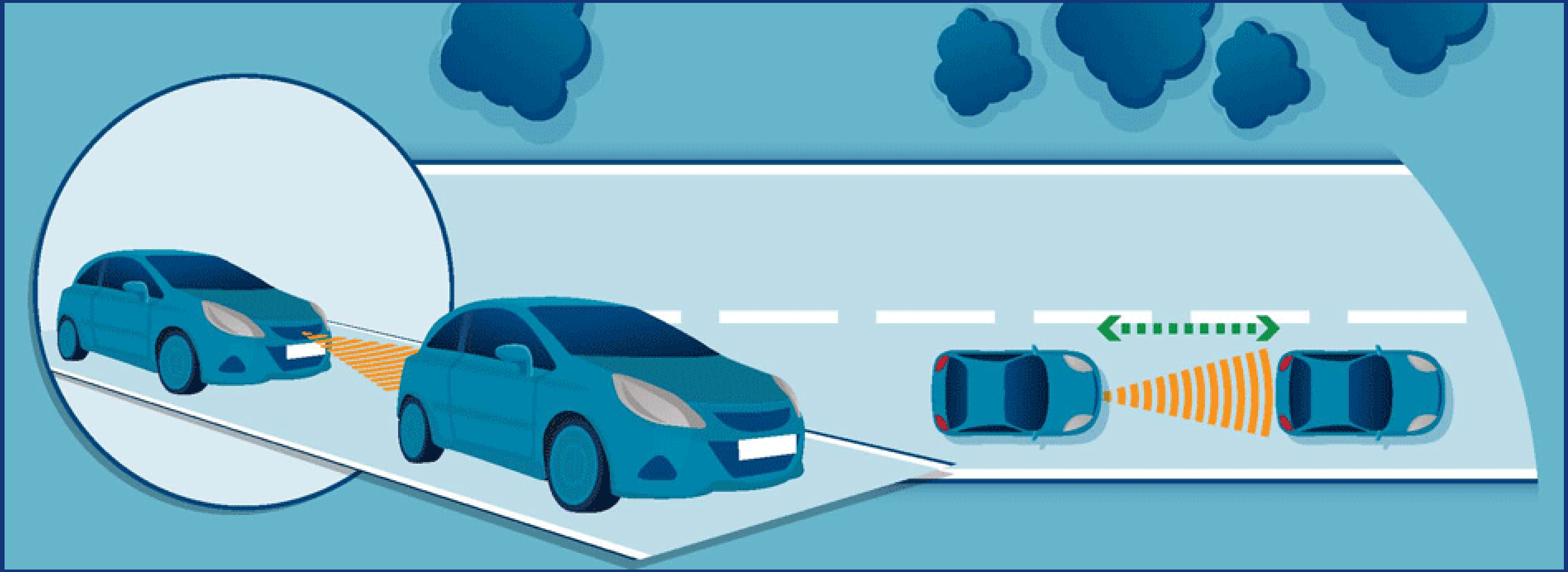



**Objectives**

**Connected Automation**

1. Develop methodologies that improve existing AMS tools to incorporate CAV technologies.
2. Develop AMS tools for and analyze potential impacts of prominent CAV applications.
3. Disseminate improved AMS tools to State and local agency partners. This includes collaborating with industry to push the adoption of CAV AMS capabilities into commercial software.
4. Develop and disseminate guidance on applying CAV AMS tools.

www.fhwa.dot.gov/research/tfhrc/projects/operations/ams/index.cfm

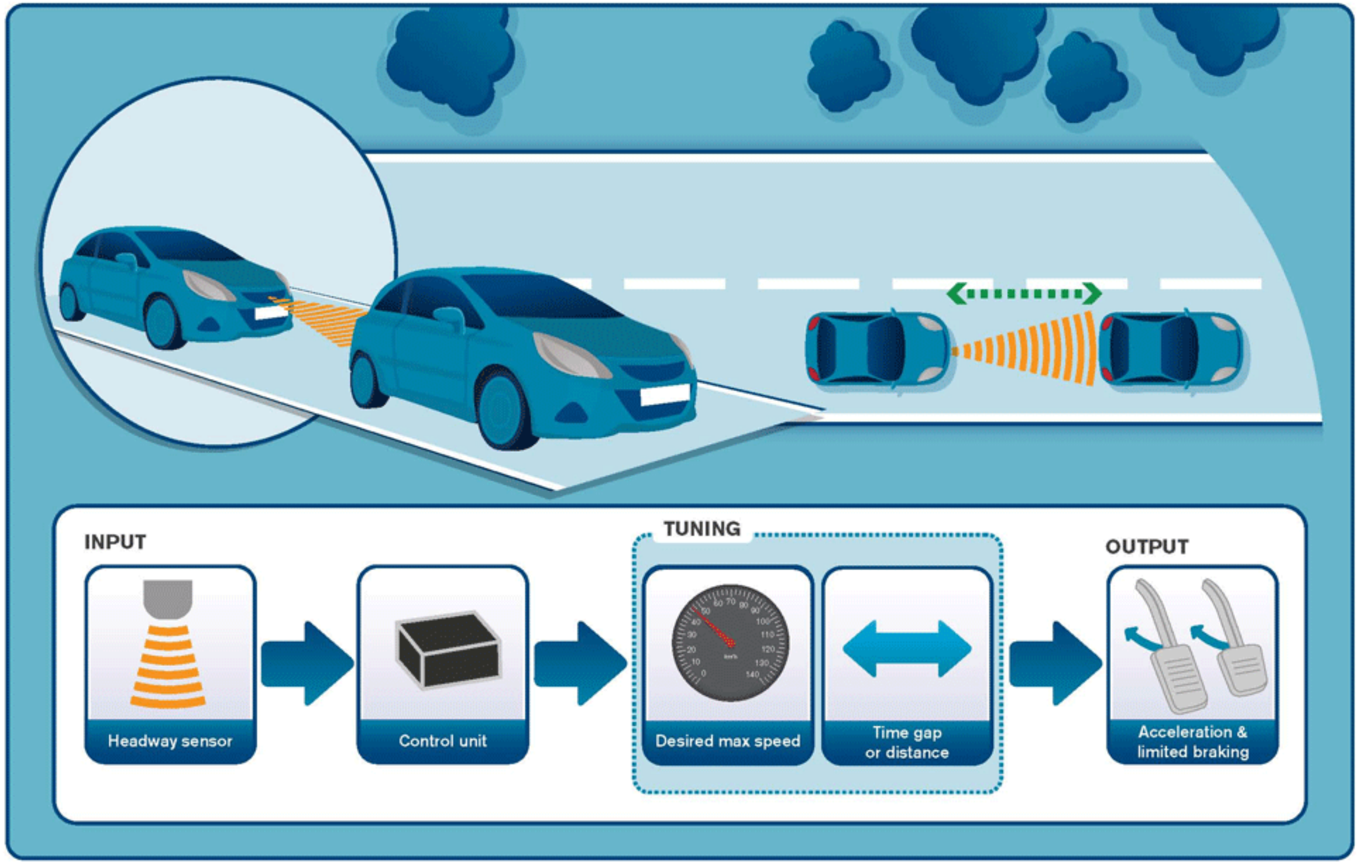


# Characterizing the Impact of Production Adaptive Cruise Control on Traffic Flow: An Investigation

# Background



- ACC utilizes radar to maintain desired constant time gap
- ACC capability in vehicles is on the rise
  - 2.2% of new 2014 models
  - 7.2% of new 2020 models
- ACC is a convenience feature
- ACC throughput estimations in literature are highly variable



# Contribution



- Comprehensive assessment of the likely impact of ACC on traffic flow
- Four ACC car-following models are simulated using VISSIM's External Driver Model functionally under consistent simulation conditions
- Models are (re)calibrated using car-following data from two ACC-equipped 2013 Cadillac SRXs
- Corridor throughput and traffic flow characteristics are explored in detail

# ACC Car-Following Models (CFMs)

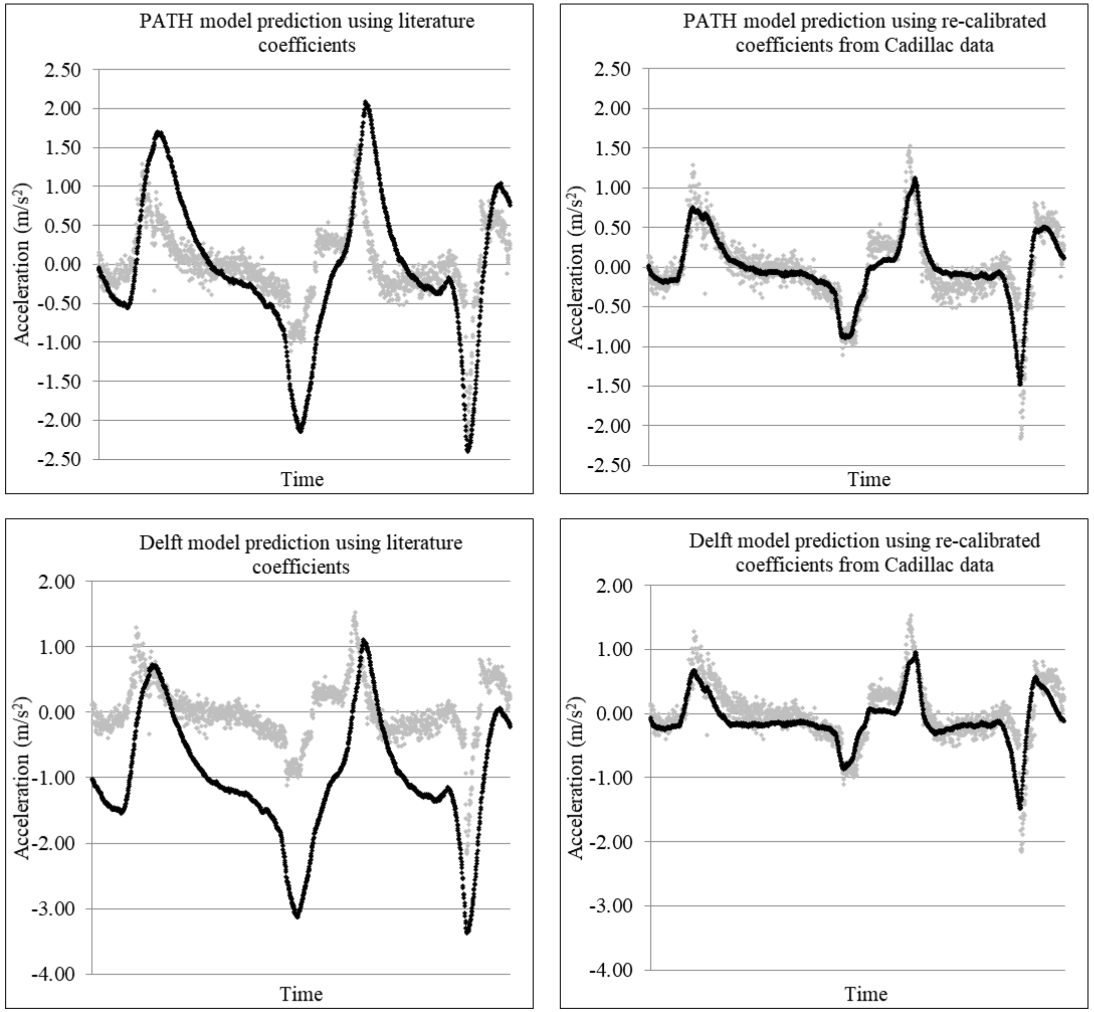


- MIXIC or AACC
  - One of the original models for automated highway systems
  - Highly unstable – lacks a collision warning system (CWS)
- Improved Intelligent Driver Model (IIDM)
  - Originally developed for naturalistic driving
  - Additional heuristics added to IIDM for ACC
  - Collision free (without human takeover)
- California PATH Empirical Model
  - Calibrated using data collected from ACC-enabled Infiniti M56s
- TU Delft Empirical Model
  - Based on PATH algorithm
  - Includes approach mode and dynamic spacing margin

# (Re)calibration of ACC CFMs



- Data collected July 2015
- Dulles Access Road, Northern Virginia
- 2013 ACC-enabled Cadillac SRXs
- Acceleration/deceleration scenarios between 25-75 mph
- Calibration optimization problem:
  - Minimize RMSE between observed and predicted acceleration
  - Split into calibration and validation dataset



# Calibration Coefficients



| Model | Calibration coefficients | Purpose of coefficient | Original coefficients found in literature | (Re)calibrated coefficients using Cadillac SRX data |
|---|---|---|---|---|
| AACC | $k_v$ | Sensitivity to difference in relative velocity | 0.58 | 0.27 |
| | $k_d$ | Sensitivity to difference in physical gap and reference distance | 0.10 | 0.06 |
| IIDM | $a$ | Represents maximum acceleration | 1.96 | 1.00 |
| | $b$ | Represents maximum deceleration | 2.94 | 2.55 |
| PATH | $k_1$ | Sensitivity to distance error | 0.23 | 0.07 |
| | $k_2$ | Sensitivity to speed error | 0.07 | 0.27 |
| Delft | $k_1$ | Sensitivity to distance error | 0.23 | 0.02 |
| | $k_2$ | Sensitivity to speed error | 0.07 | 0.33 |

# Microsimulation Case Studies

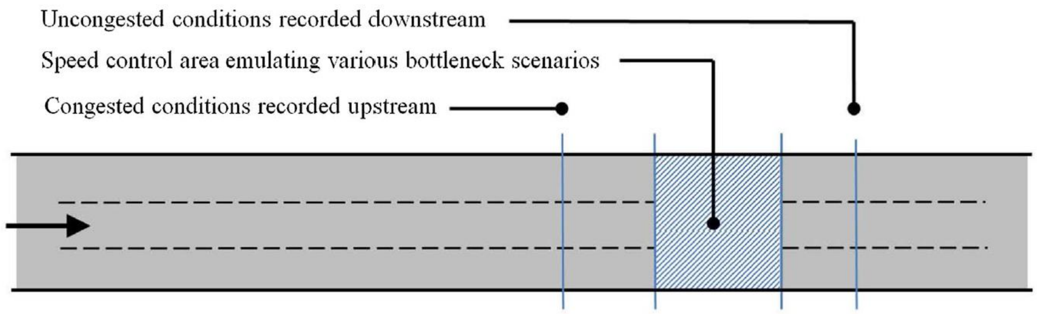


- Vehicle Control
  - ACC CFM – longitudinal control
  - Software lane changing logic – lateral control
  - Human takeover as prescribed by ACC CFM
- Assumptions:
  - MP rates | [0%-100%], 25%
  - Time gaps | [0.9s, 1.1s], [50.4%, 1.1s; 18.5%, 1.6s; 31.1%, 2.2s]
  - Desired speed distribution | [55-65mph]
  - Ten random seeds

# Microsimulation Case Studies

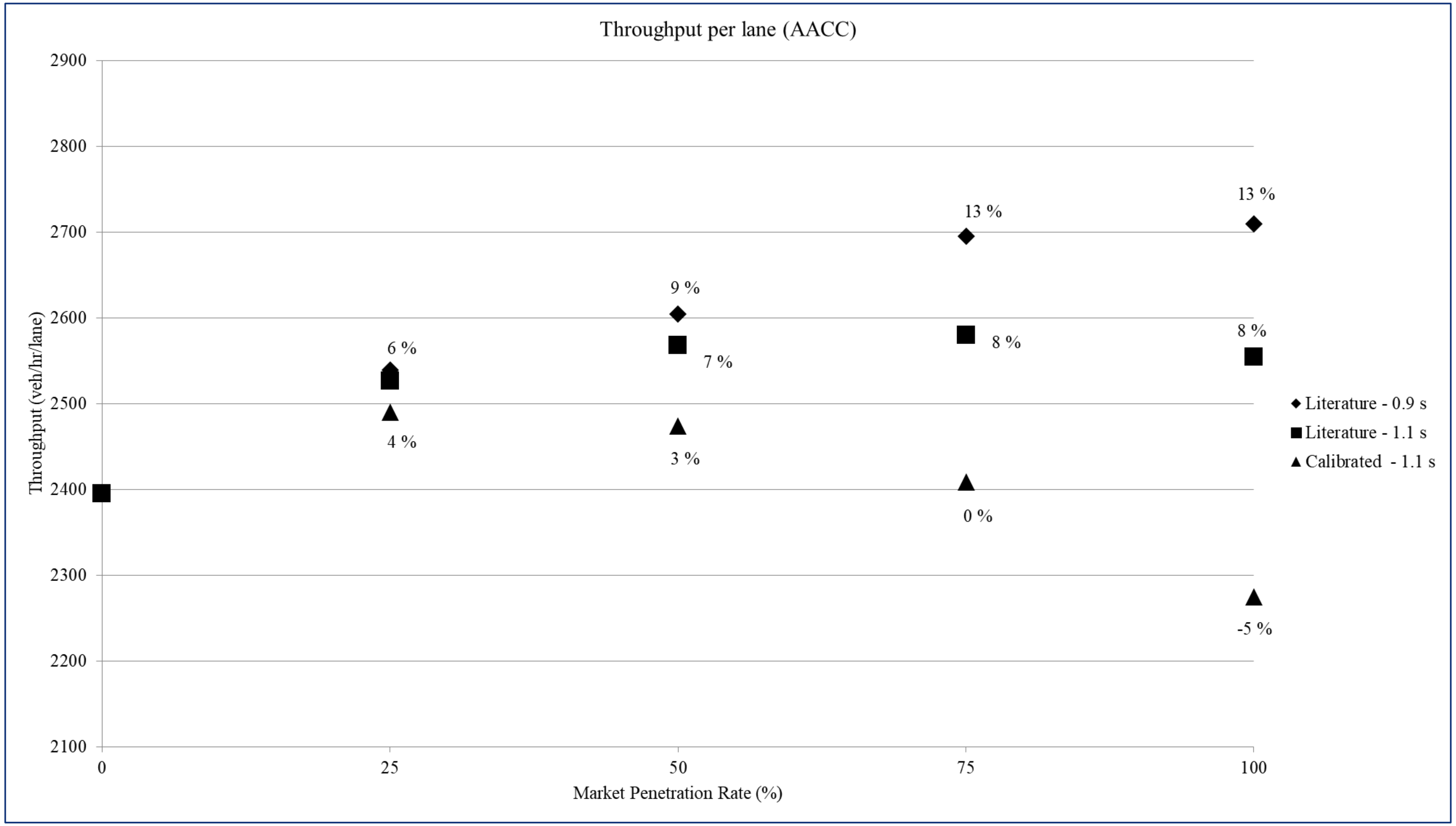


- Throughput Analysis
  - Four lane basic segment
  - Demand | [1800-3000vphpl], 200vphpl
  - Over 4200 simulations
- Traffic Flow Characteristics Analysis
  - Three lane basic segment
  - Random reduced speed zones to induce bottlenecks
    - Upstream of emulator – congested regime
    - Downstream of emulator – uncongested regime



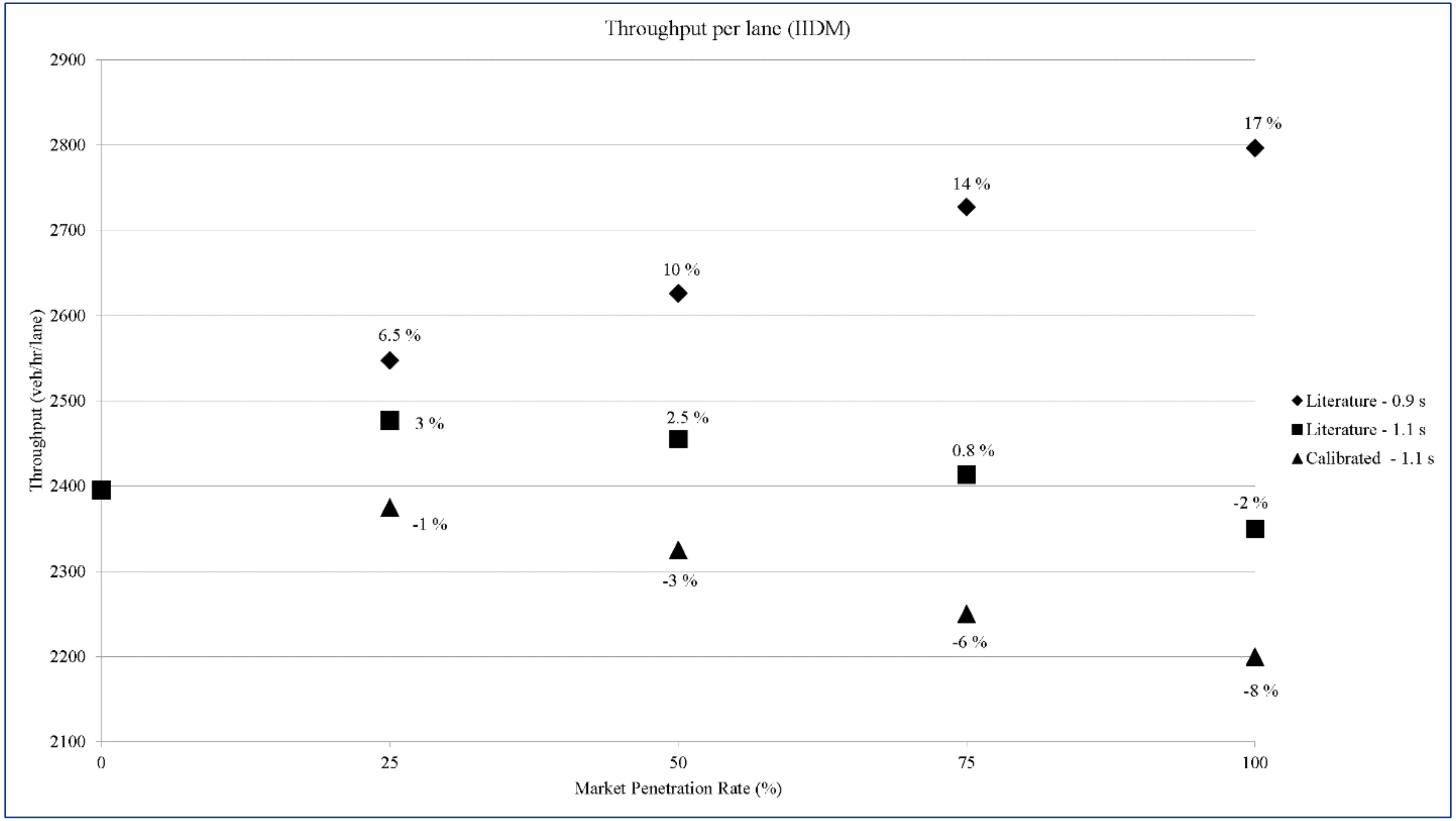
# Throughput Analysis – MIXIC/AACC





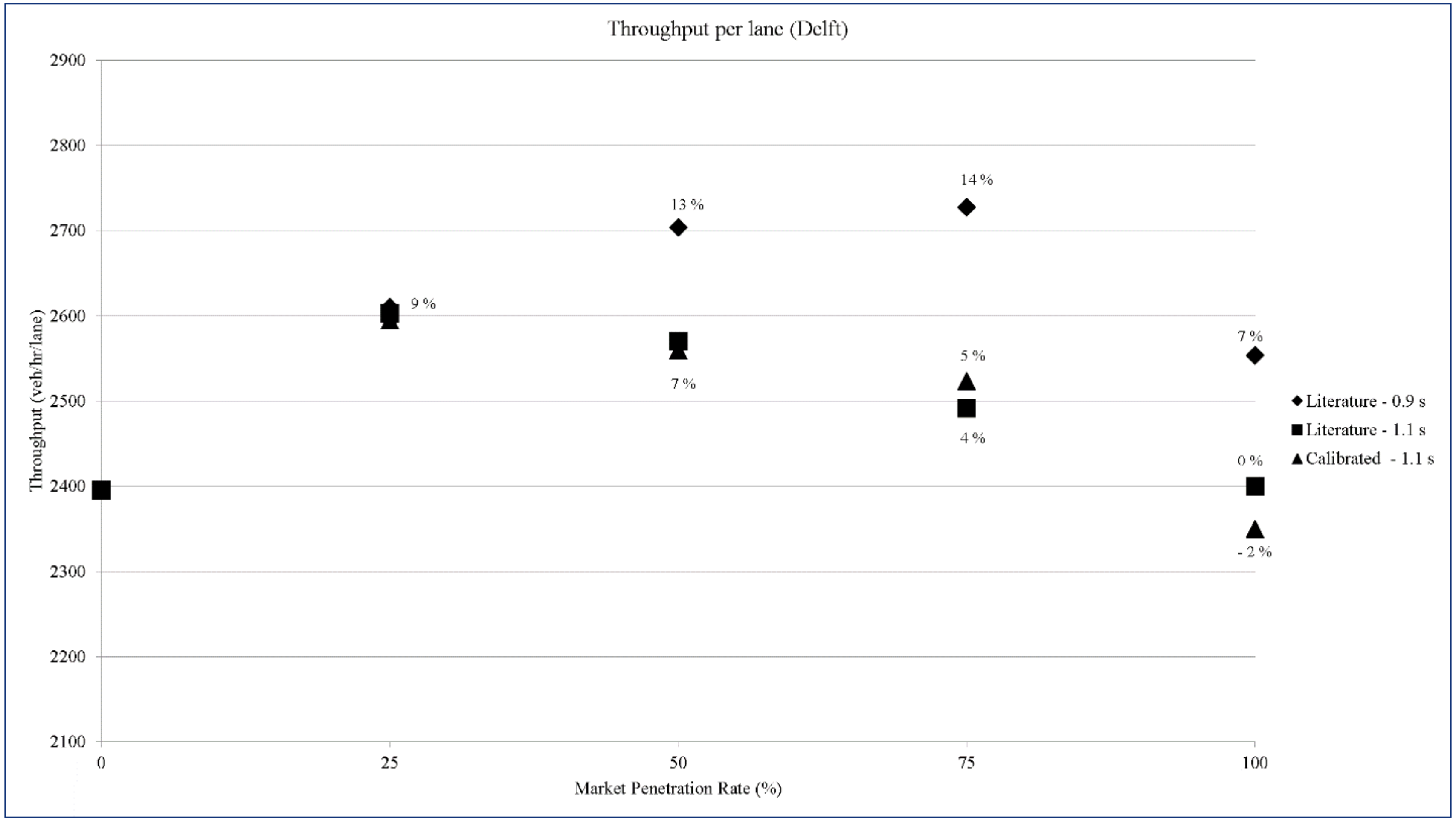
# Throughput Analysis – IIDM





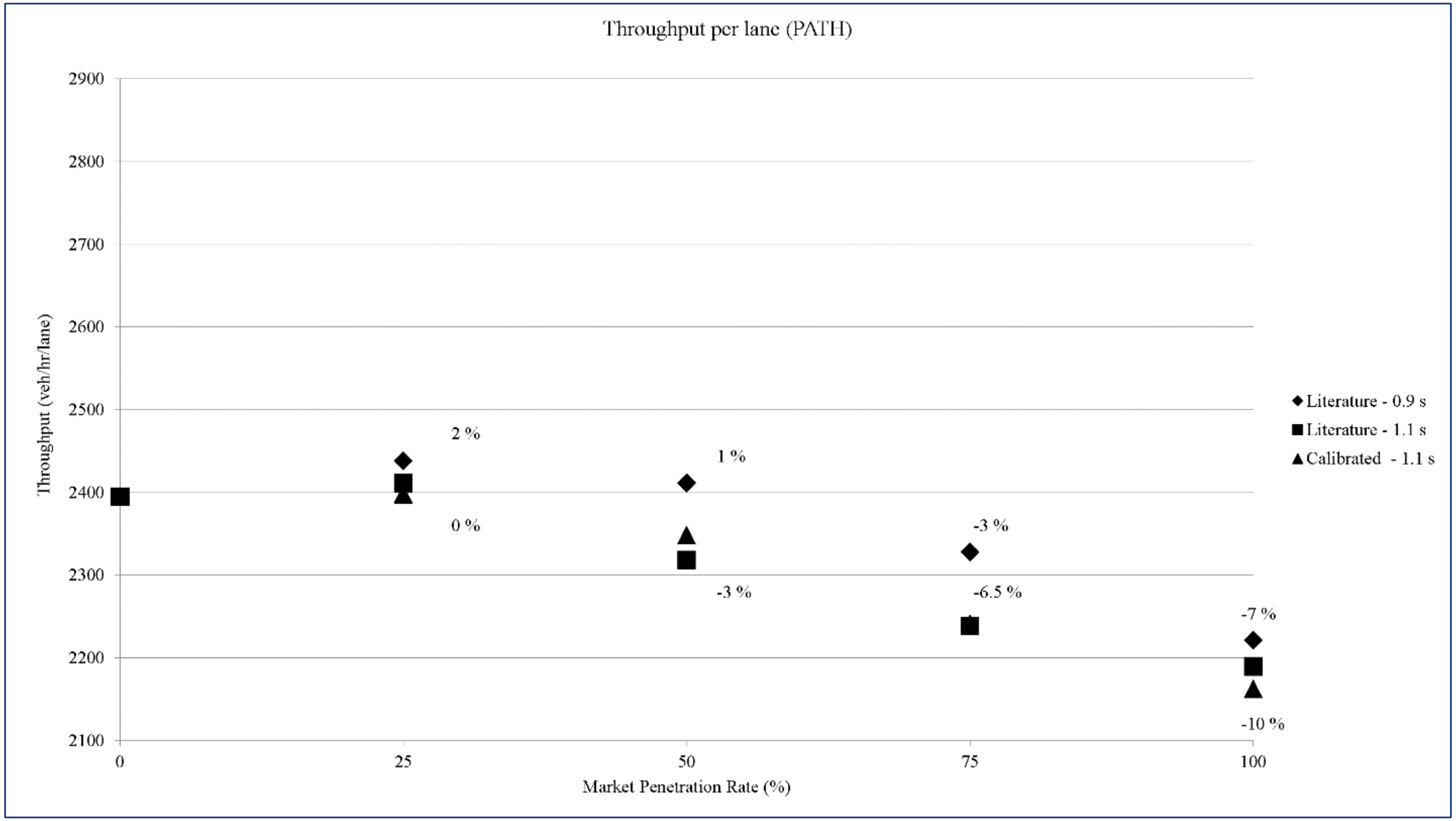
# Throughput Analysis – Delft





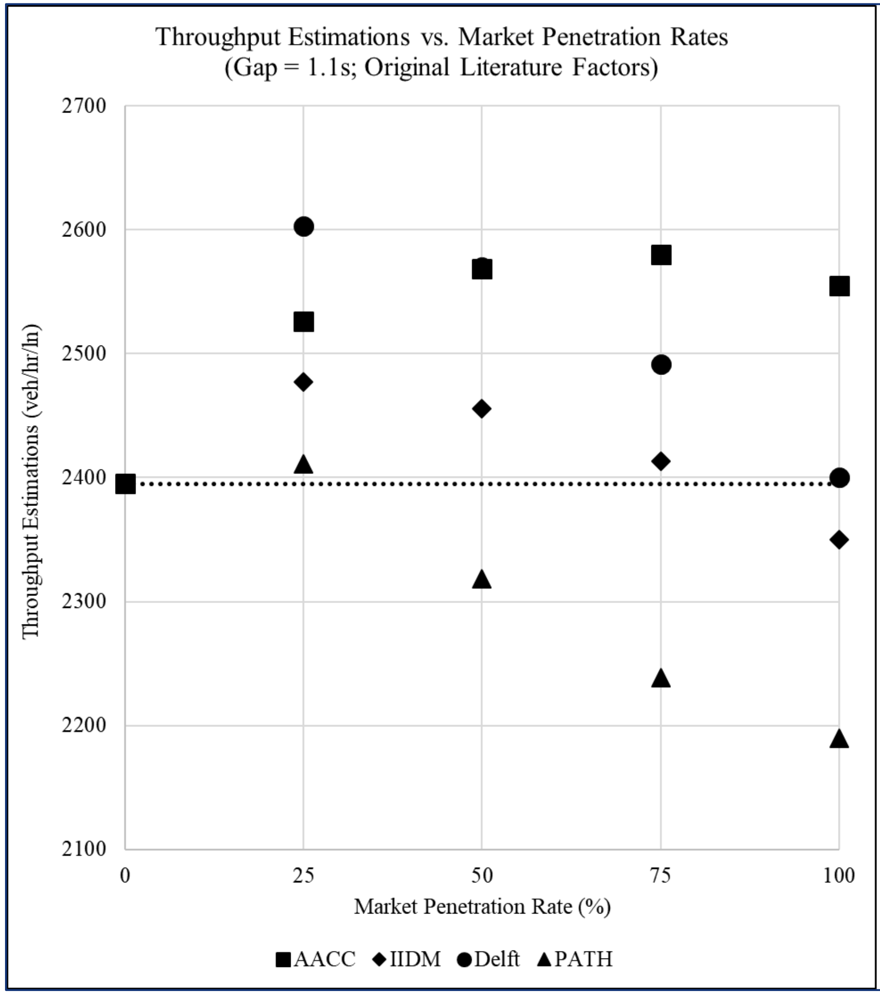
# Throughput Analysis – Path

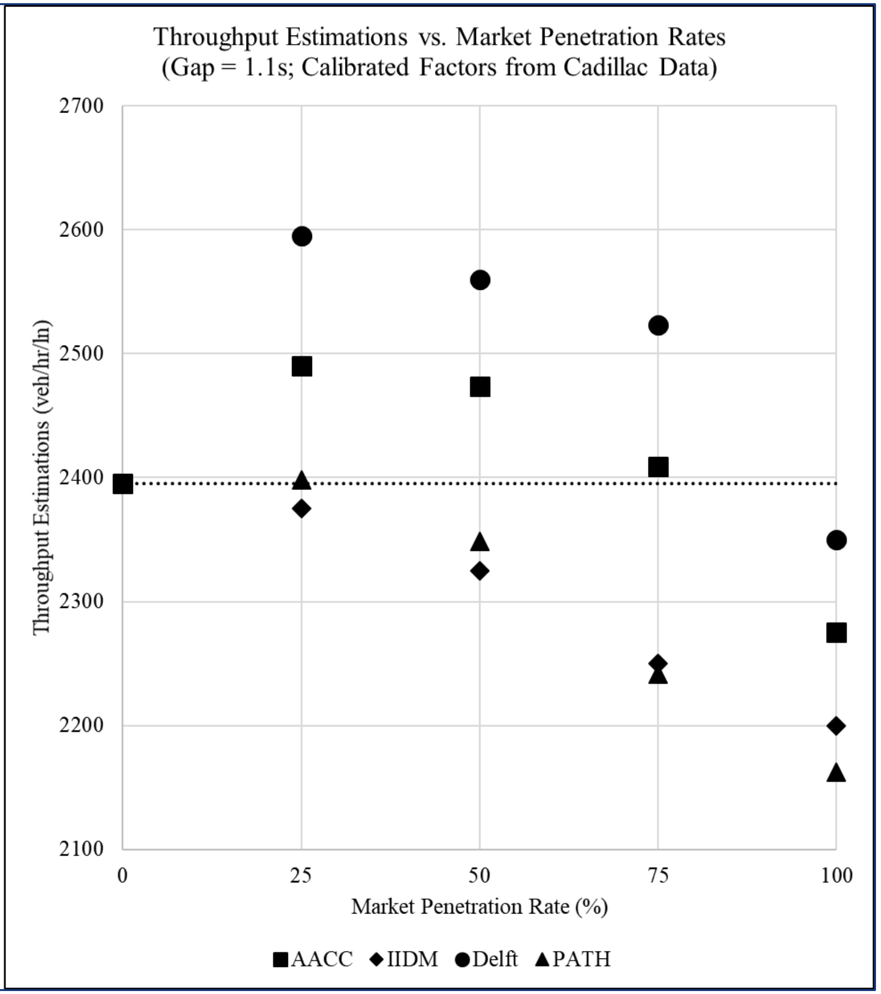




# Throughput Analysis – Comparison

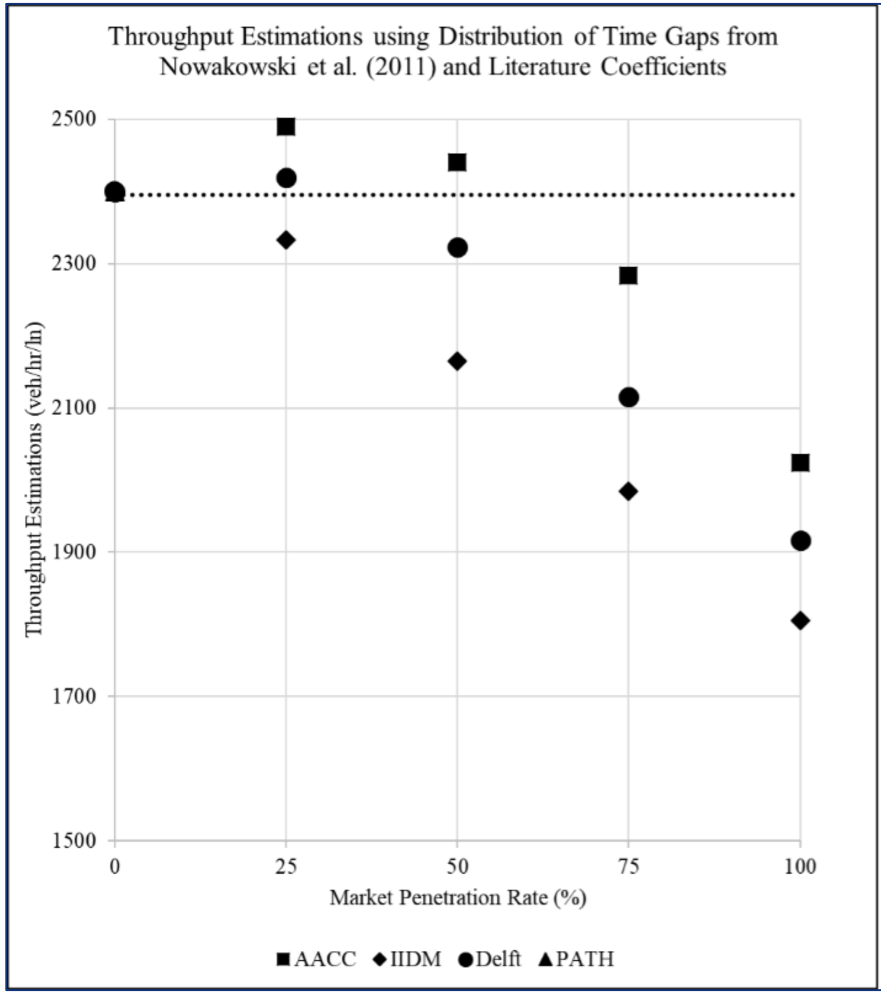


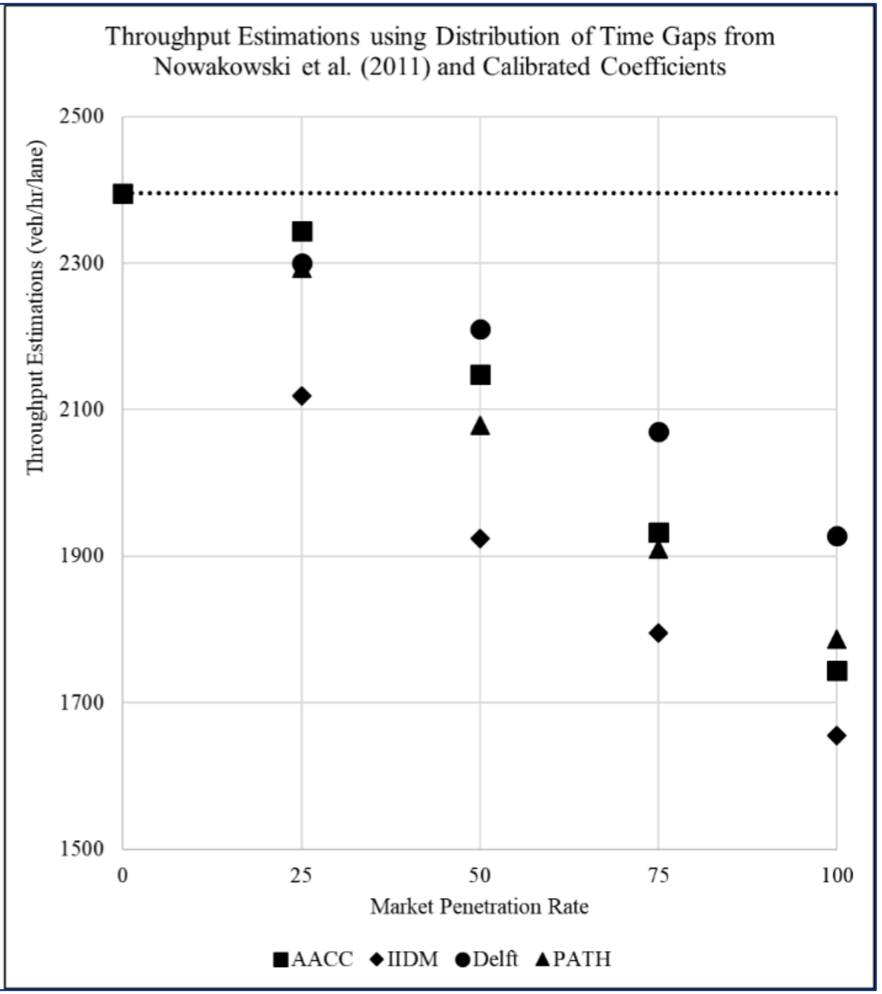


# Throughput Analysis – Gap Distribution



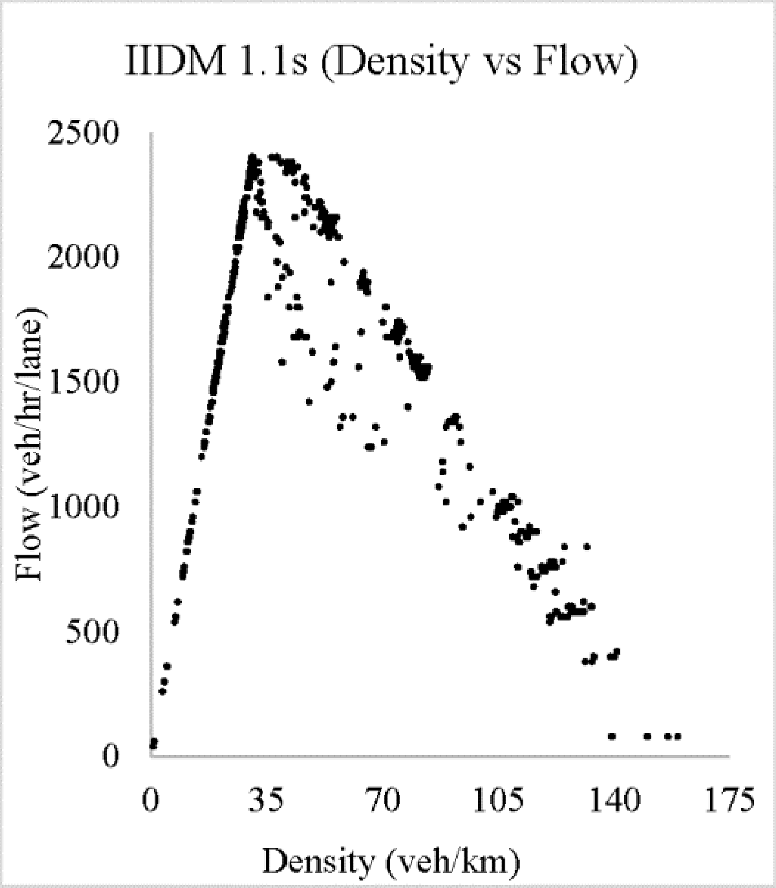


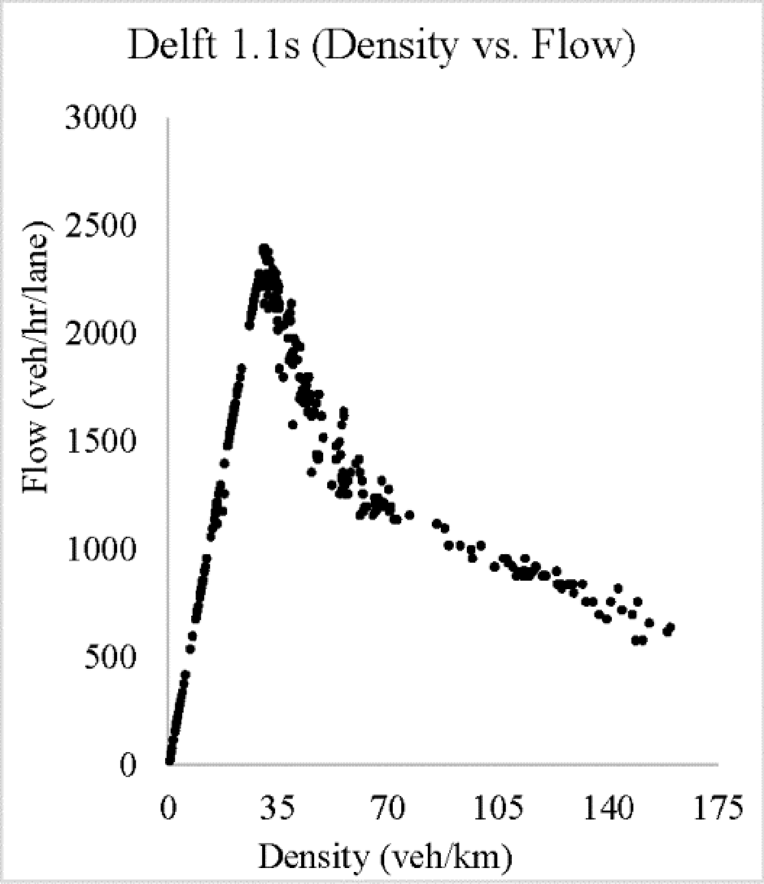



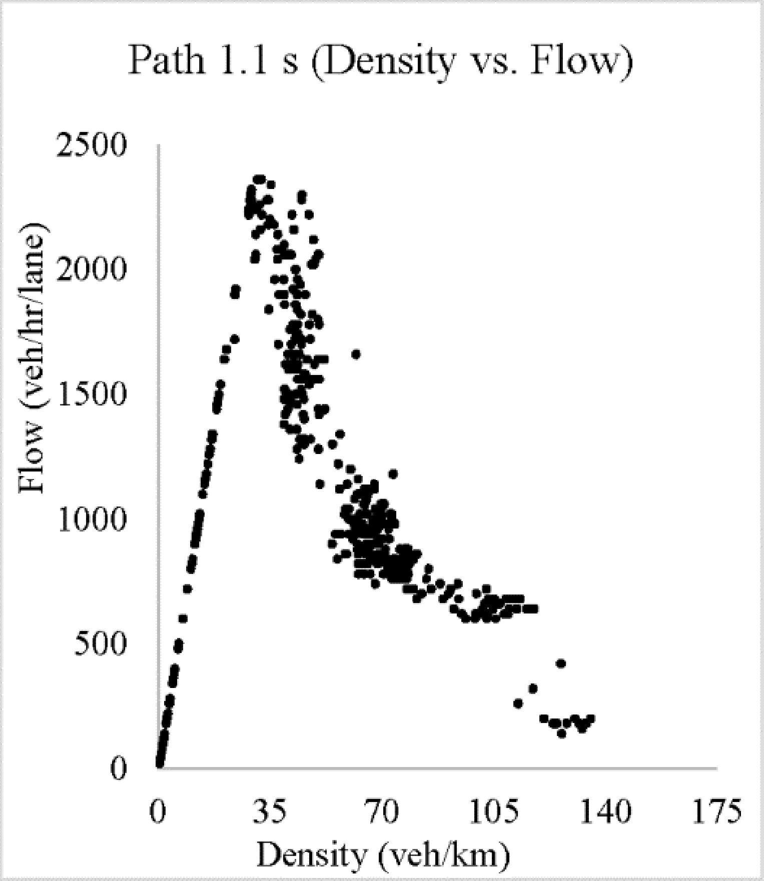

50.4% - 1.1s
18.5% - 1.6s
31.1% - 2.2s

# Traffic Flow – 100% MP



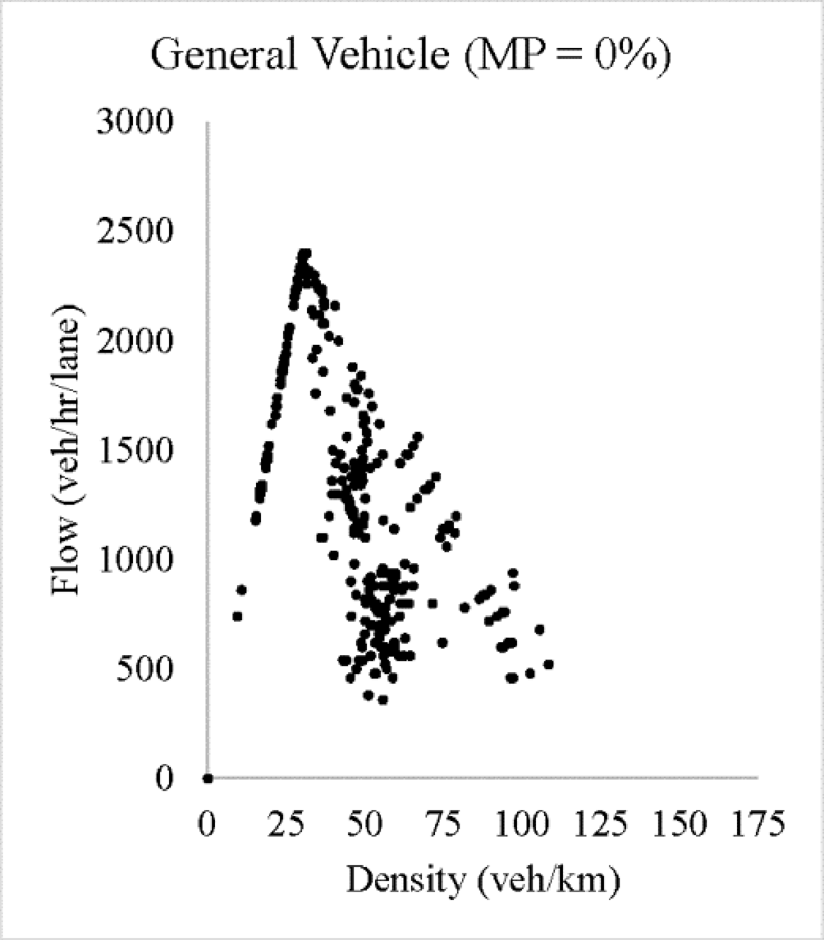


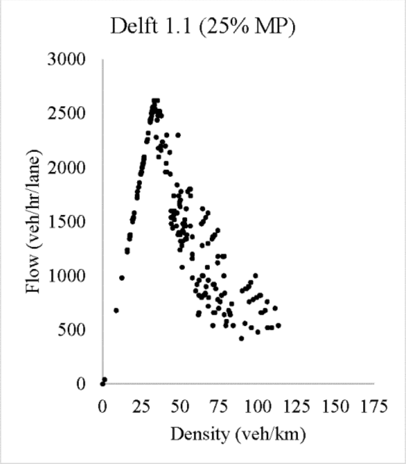



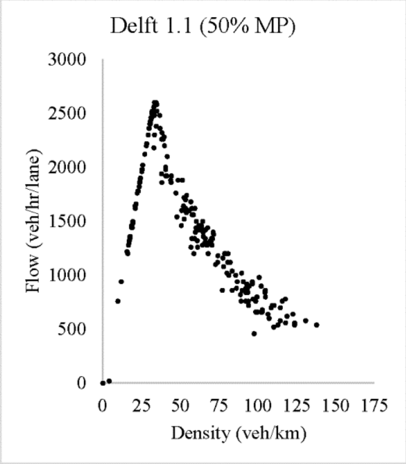



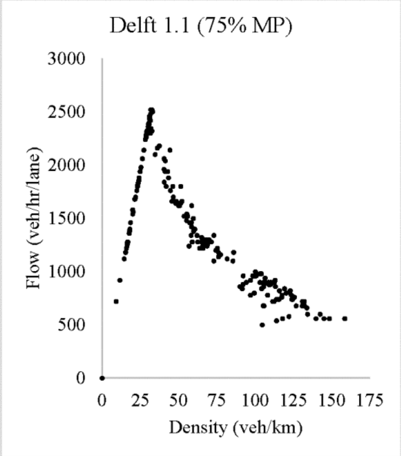
# Traffic Flow – 100% MP

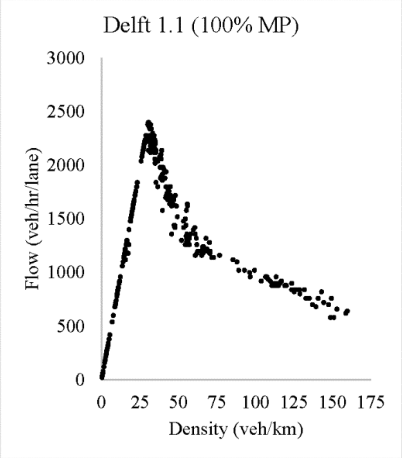




# Conclusions



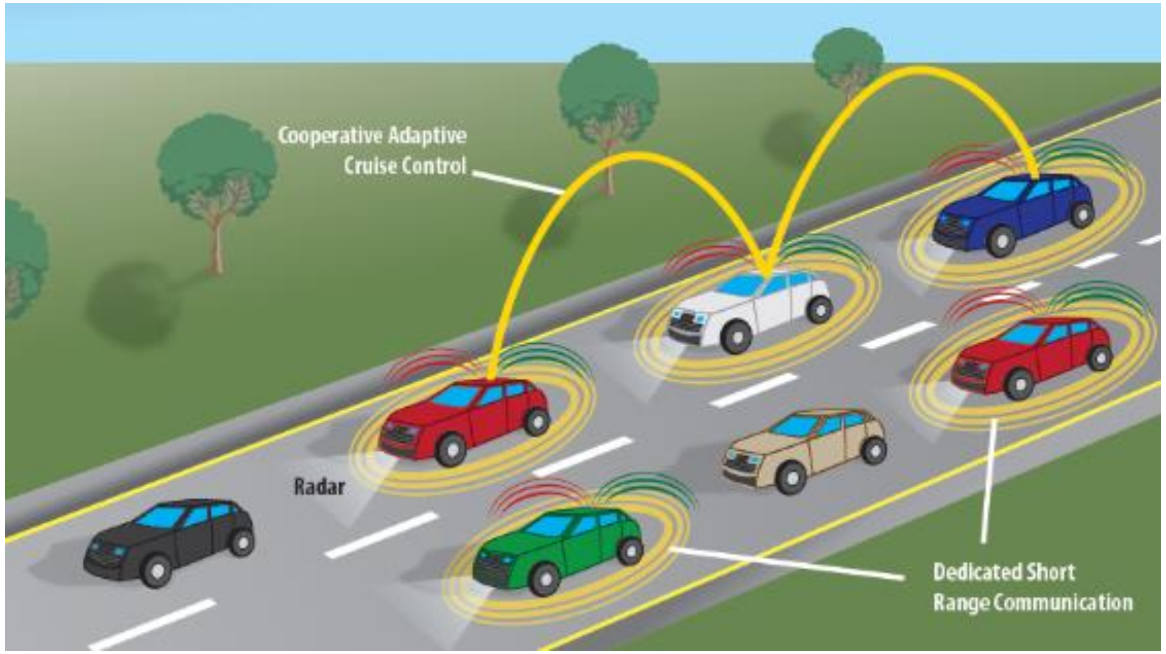
- MIXIC/AACC CFM is most sensitive to calibration coefficients
- IIDM ACC CFM is most sensitive to the desired time gap
- PATH & Delft empirical ACC CFM not sensitive to coefficients
- ACC MP rates ↓, throughput ↑
- Marginal impact on throughput when MP rate ≤ 50%
- MP rates > 50%, average throughput ↓
- Scatter in the fundamental diagram ↓ as MP ↑
- Congested regime of FD is sensitive to the ACC CFM


# Dynamic Traffic Assignment of Cooperative Adaptive Cruise Control

# Background



- CACC utilizes low-latency V2V communication (DSRC)
- Potential to significantly increase freeway capacity (shortened headways)
- Previous CACC studies limited in scope
  - Small corridor studies
  - Rely solely on microsimulation
  - Ignore impacts at ingress/egress points, network-wide impacts



# Contribution



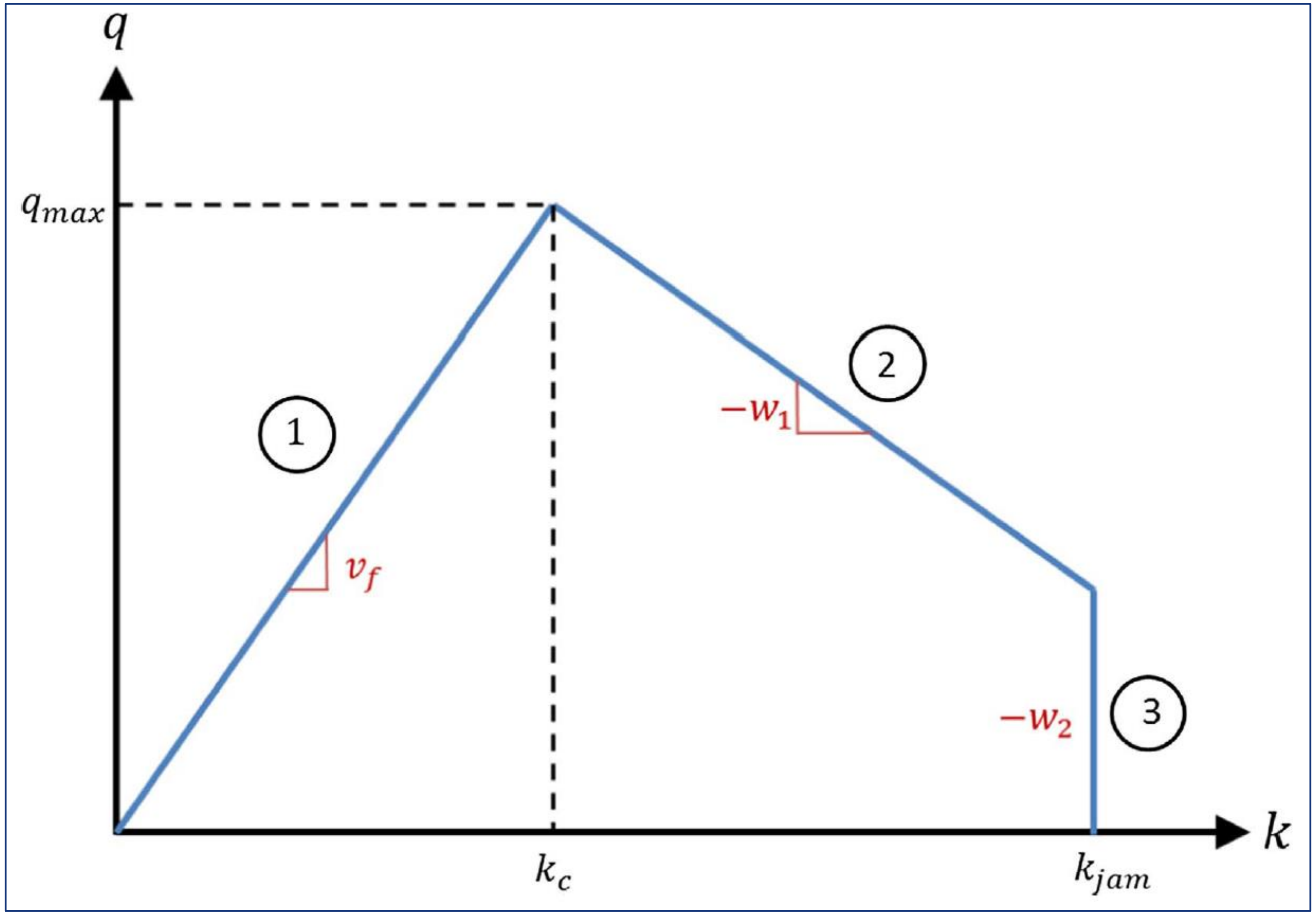
- Derived fundamental diagram (flow-density relationship) from MIXIC car-following model for CACC
- Verified relationship using microsimulations in VISSIM's External Driver
- Created link transmission model (LTM) from derived relationship; created a mesoscopic model
- Quantified errors in the created LTM
  - Time step
  - Link length
- Conducted series of case studies
  - Corridor example
  - Subnetwork example

# Derived Fundamental Diagram



- Mathematically derived from MIXIC car-following model for CACC
- Assumed piecewise linear fundamental diagram
- Assumed steady-state conditions

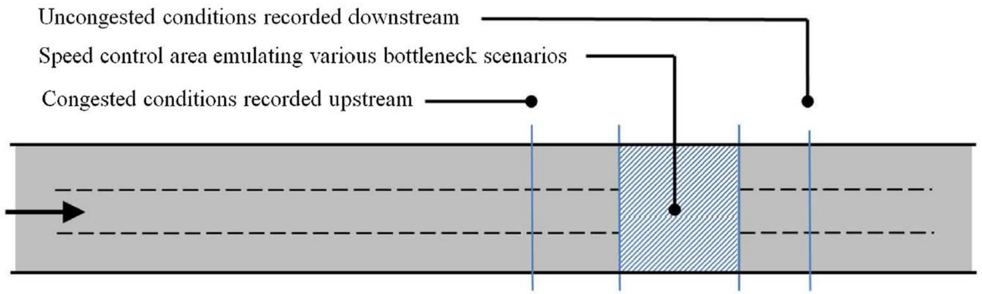
$$q = \min \begin{Bmatrix} (1) & v_f k & 0 \leq k < k_c \\ (2) & \frac{1-kl}{t_{\text{system}}} & k_c \leq k < k_{\text{jam}} \\ (3) & \frac{v}{s_{\min}+l} & k = k_{\text{jam}} \end{Bmatrix}$$

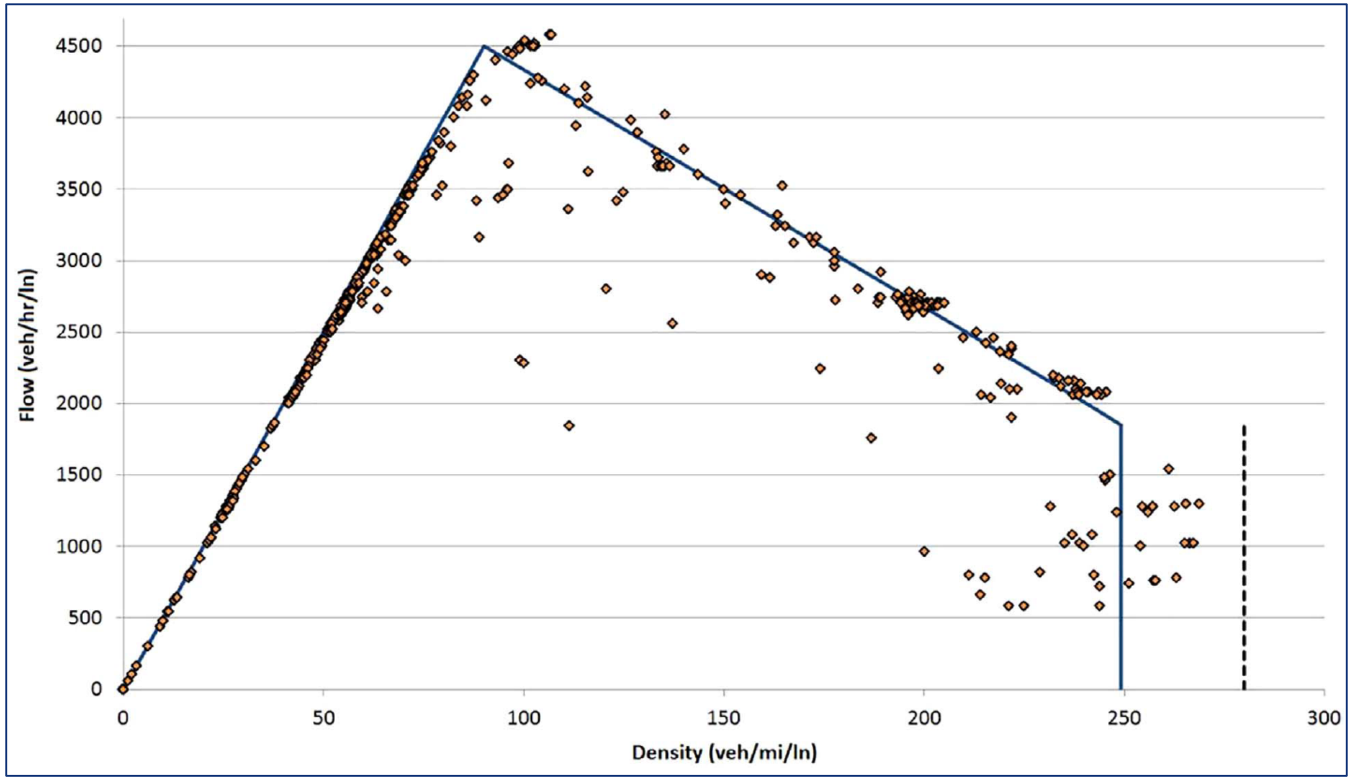


# Validation of Fundamental Diagram



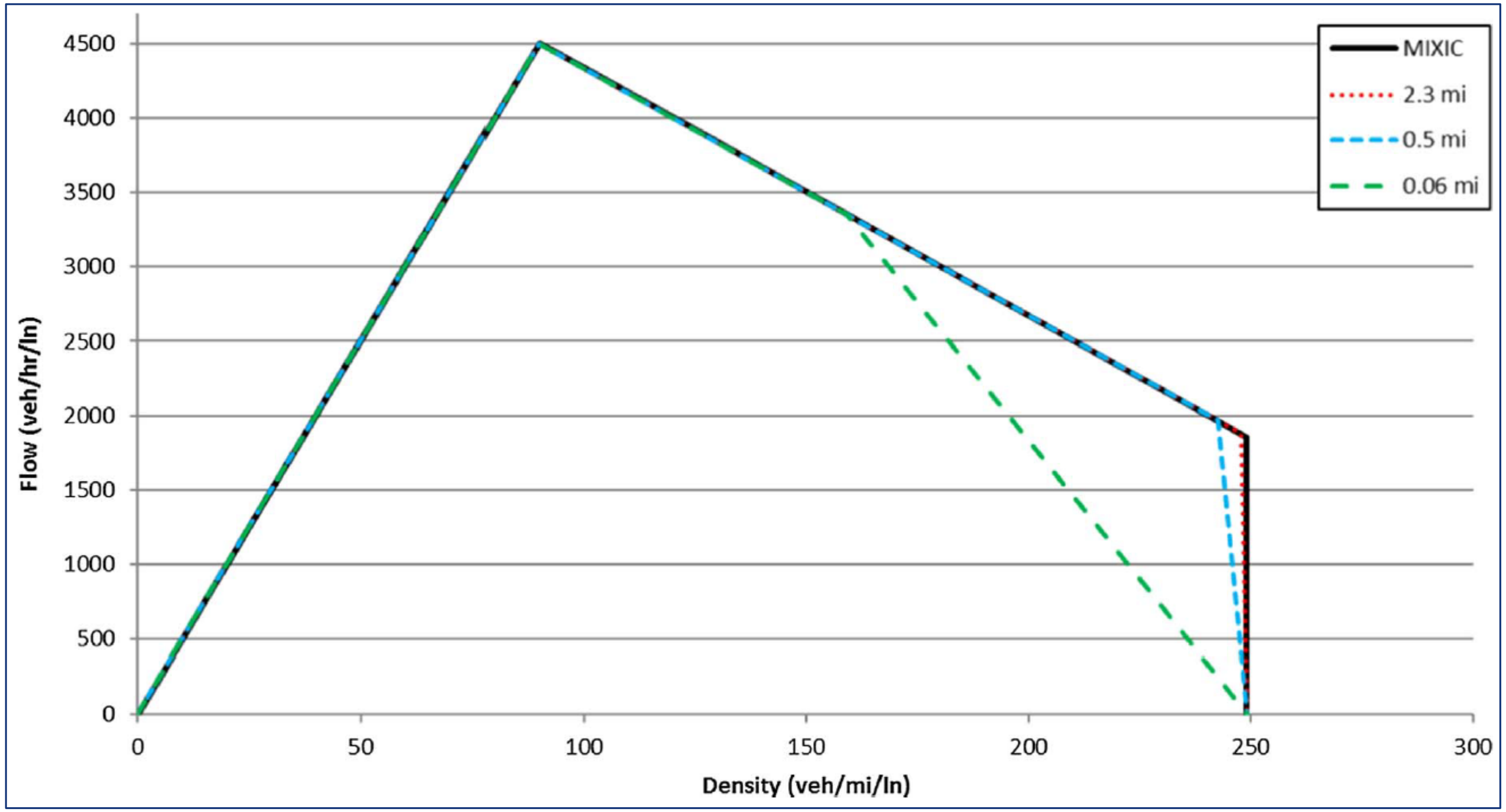
- Assumptions
  - $l = 14.6$ ft
  - $t_{system} = 0.6$ s
  - $s_{min} = 6.5$ ft
  - $v_f = 50$ mph



# Errors due to Link Independence Constraint

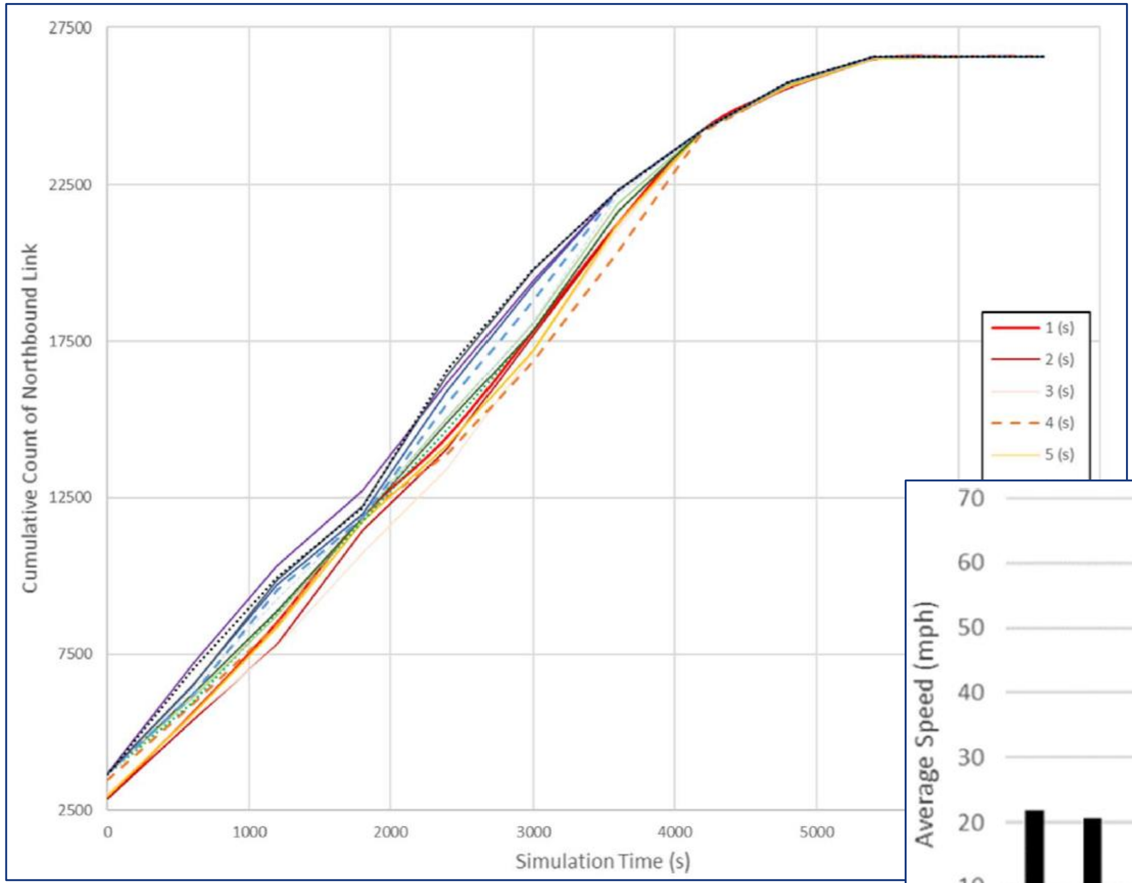


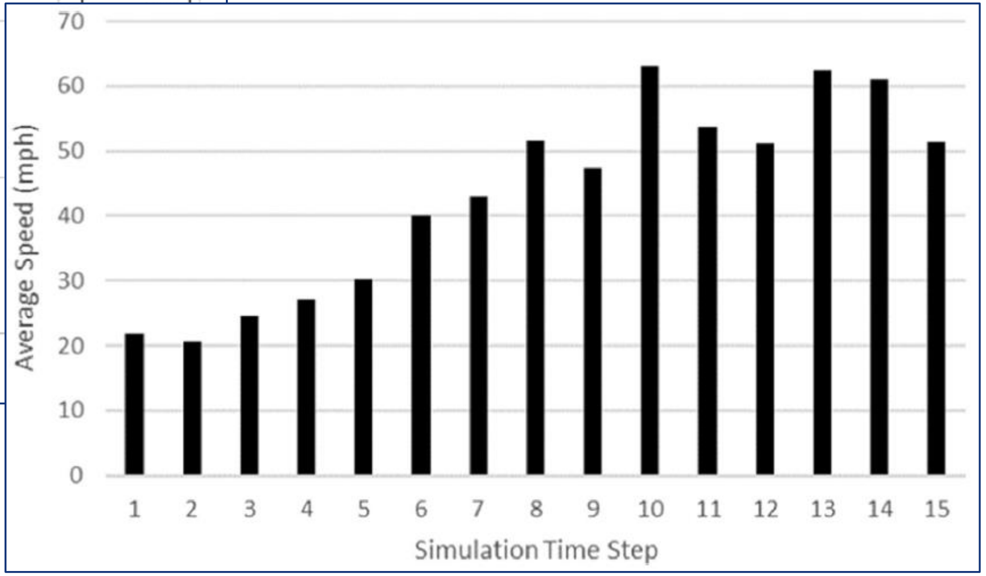


# Errors due to Link Independence Constraint



I-35 north of Round Rock, TX



# Case Study: Corridor Example



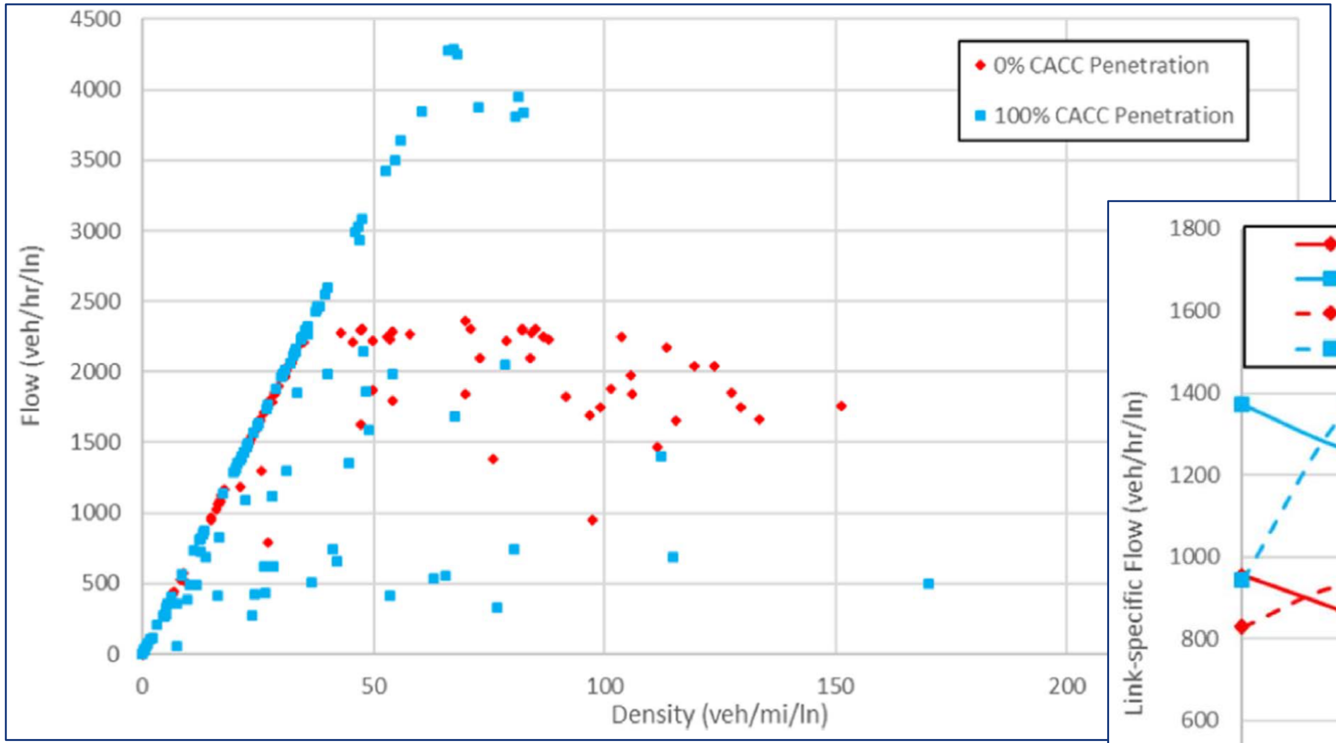
I-35 north of Round Rock, TX

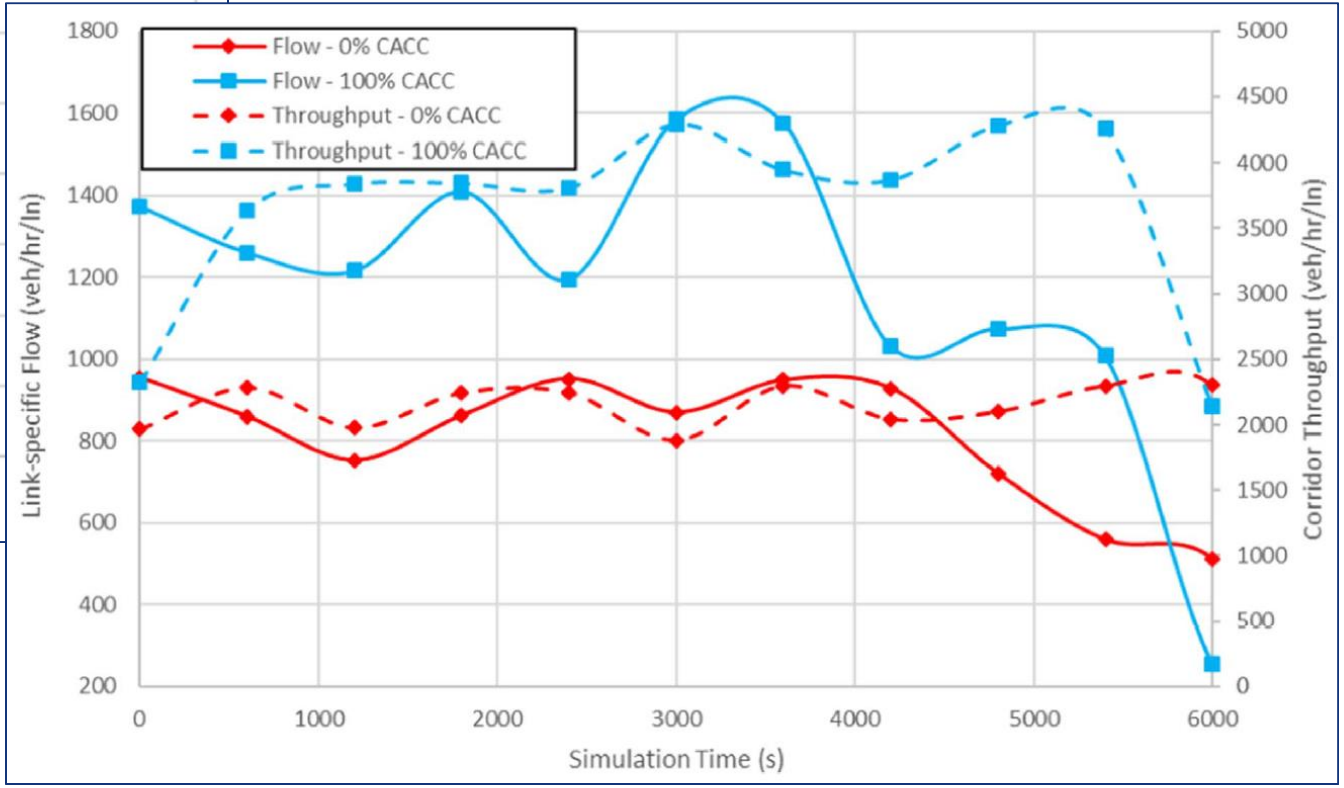
| Demand scenario | NB peak demand (veh/hr/ln) | SB peak demand (veh/hr/ln) |
|---|---|---|
| A | 323 | 260 |
| B | 646 | 520 |
| C | 1292 | 1040 |
| D | 1938 | 1560 |

| Demand Scenario | Sim. Model | 0% CACC Penetration | | 100% CACC Penetration | | Improvement between 0% and 100% |
|---|---|---|---|---|---|---|
| | | N. Test Runs | Average Demand | N. Test Runs | Average Demand | % Change Total Travel Time |
| A | VISSIM | 10 | 2420 | 10 | 2420 | 0.04% |
| | DTA | | 2420 | | 2419 | 0.02% |
| B | VISSIM | 10 | 4802 | 10 | 4801 | 0.05% |
| | DTA | | 4801 | | 4792 | 0.10% |
| C | VISSIM | 10 | 9621 | 10 | 9620 | −0.81% |
| | DTA | | 9619 | | 9569 | −7.60% |
| D | VISSIM | 10 | 14,412 | 10 | 14,412 | −23.61% |
| | DTA | | 14,412 | | 14,255 | −31.66% |

# Case Study: Corridor Example

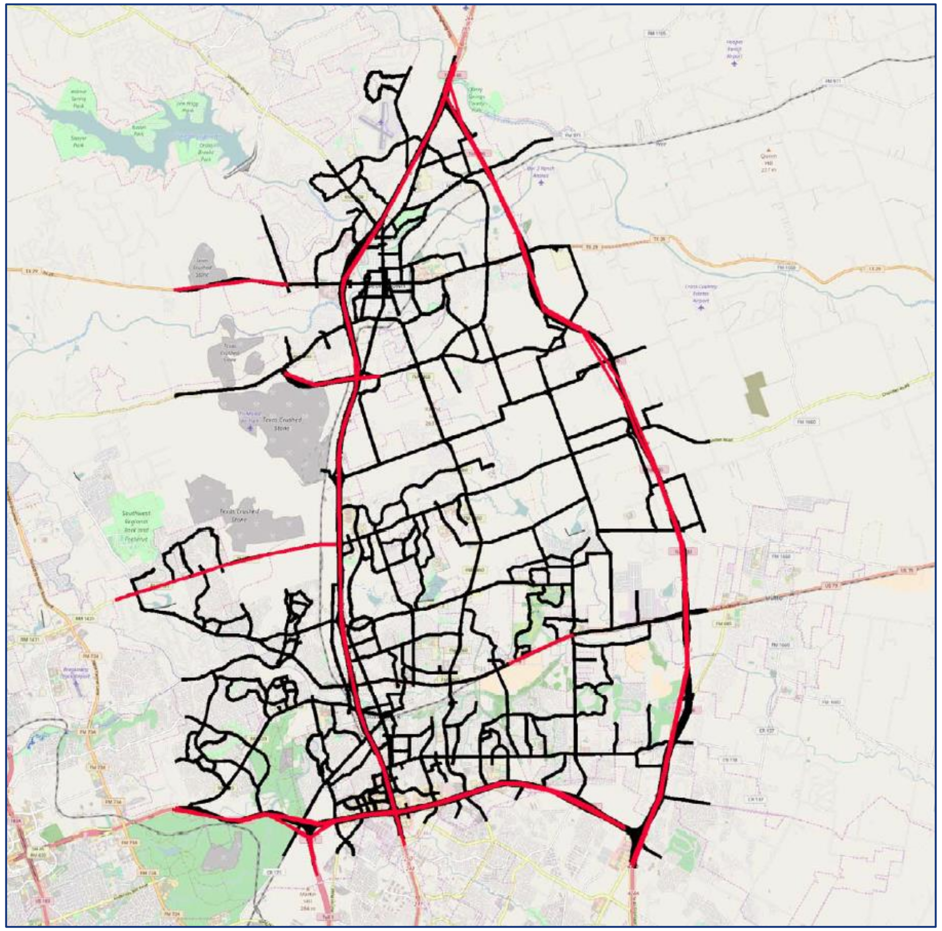




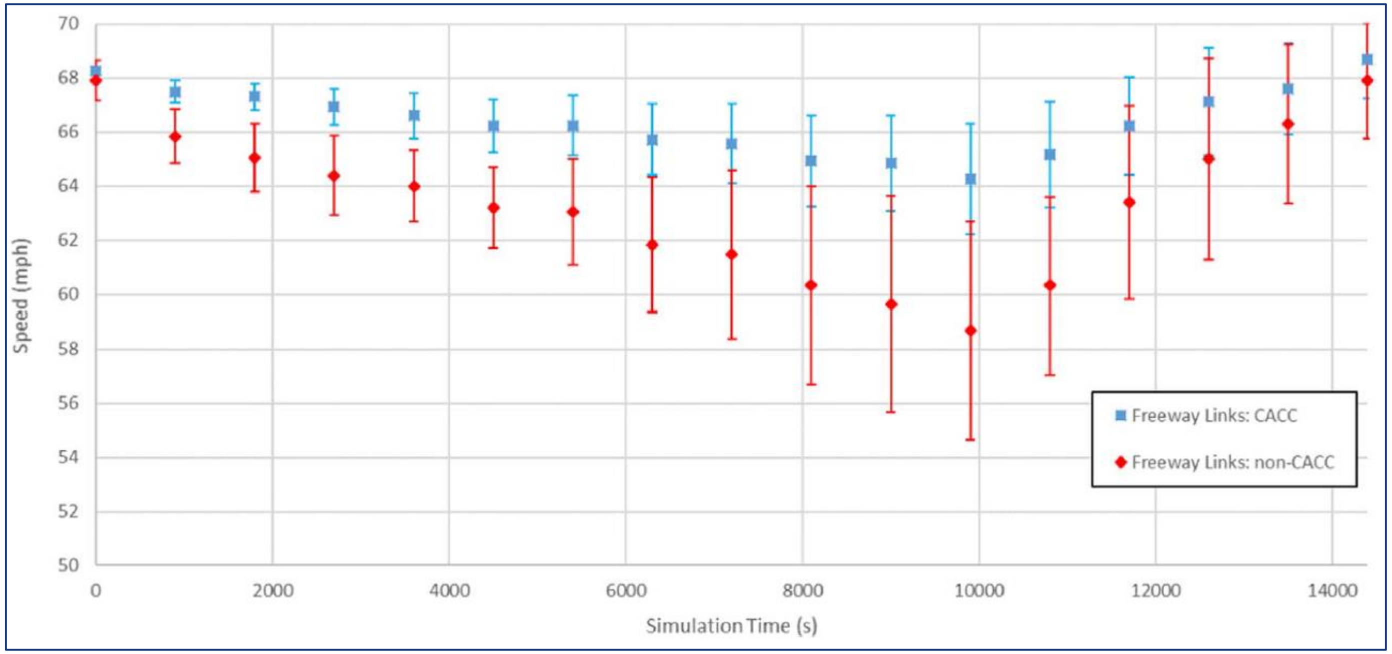



# Case Study: Subnetwork Example





Subnetwork of Round Rock, TX



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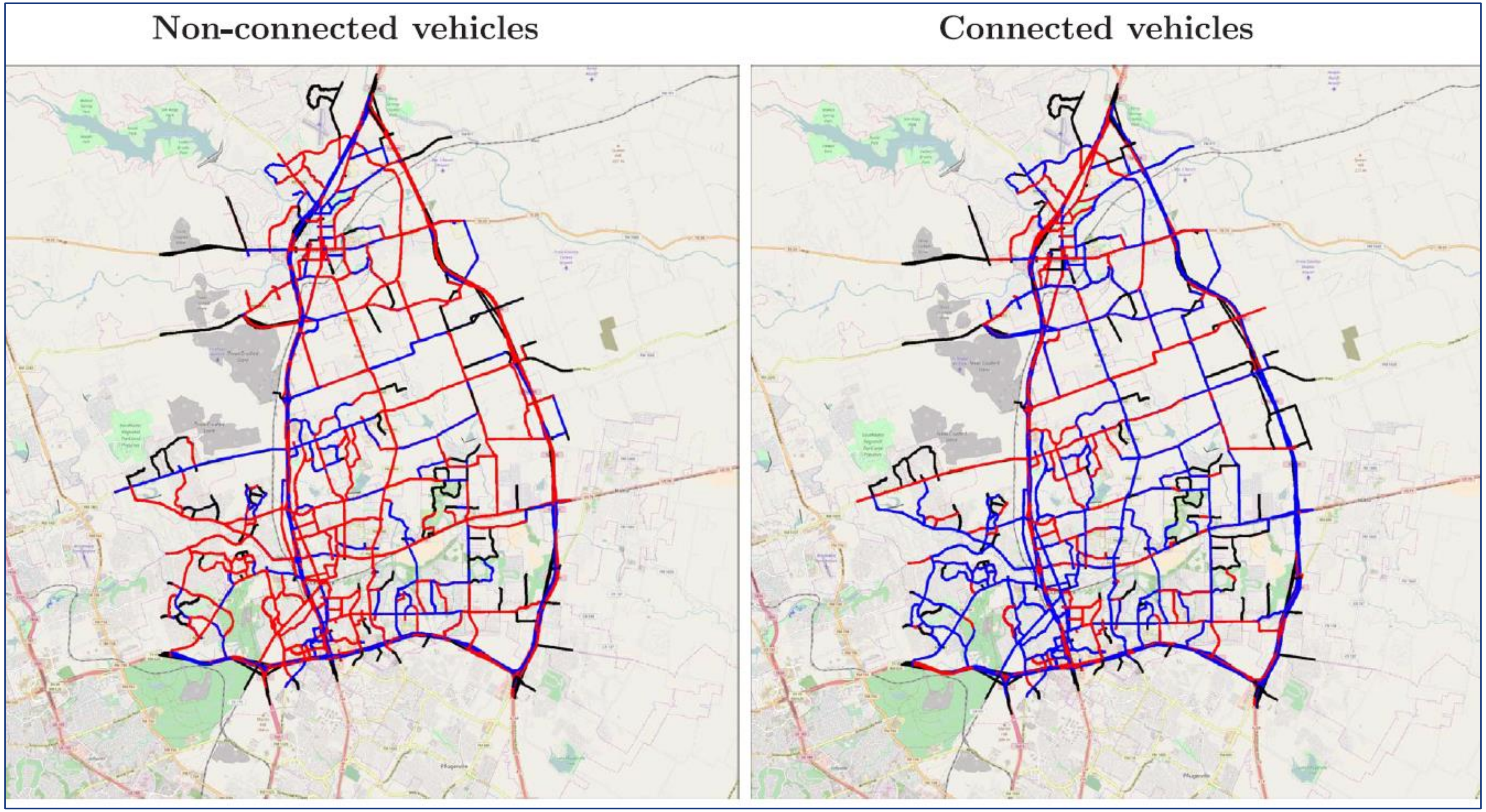

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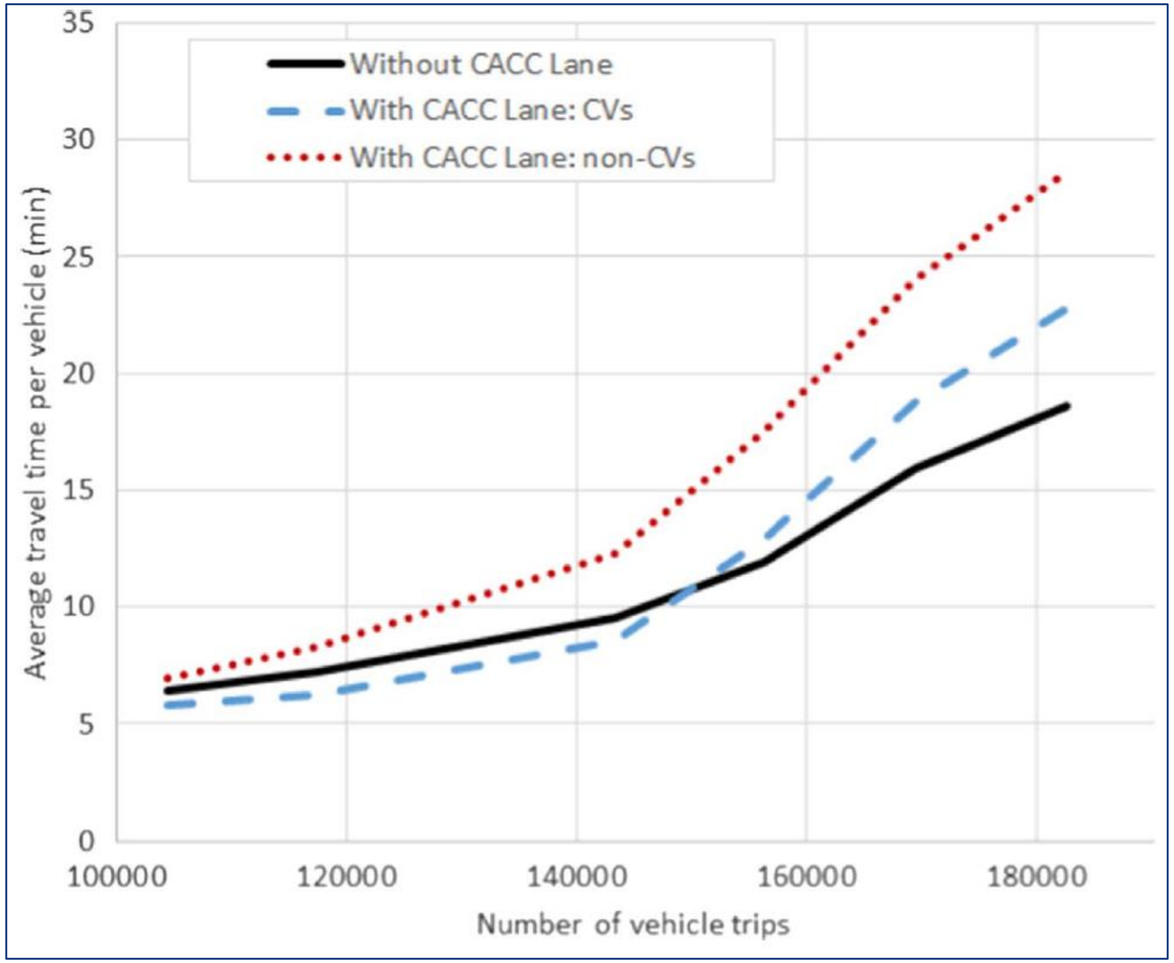

# Conclusions



- Unusual shape of fundamental diagram causes errors in created LTM
- At reasonable freeway link lengths (1 km) and short time steps, minimal error
- Travel time reductions from CACC at high demand (corridor case study)
- Decreases in freeway congestion, but average travel times for the entire network increased due to route choice,
- Effective deployment of CACC-exclusive lanes requires DTA analyses that include user route choice

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Dynamic traffic assignment of cooperative adaptive cruise control

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# Questions?



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